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Cover photo credit: CSS/CCGS *Hudson* (1963-2002), Canadian oceanographic research vessel. (Photo - BIO Archives)

Back cover inset photo credits: Top: American red squirrel, *Tamiasciurus hudsonicus*; Centre Left: Crocuses, *Crocus sativus*, in a spring garden; Centre Right: an indigenous sculpture, "Mother bear prays for earth healing", City Hall, St. Albert, AB; Bottom: a climbing hydrangea, *Hydrangea petiolaris*, a popular perennial garden flowering plant." (Photos by Peter Wells)

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EDITORIAL

On making the right decisions in urban planning and coastal management – a role for the NSIS?

There can often be a disconnect between important societal needs and the actions and attitudes of elected politicians, policy makers, and the responsible bureaucracies. We hope that this editorial, and you the reader, will stimulate a discussion within the NSIS about how, on important issues, information (social and scientific) can best be considered and be influential at various policy and decision-making interfaces. This is a topic of much interest today on many fronts (for example, see Dalhousie University EIUI project www.eiui.ca and Macdonald *et al.* 2016). Two local high-profile issues are of current concern to us and are briefly discussed below. The reader will likely think of others!

The first issue is the current rush by the Halifax City Council to densify the city core, including new major housing developments in places such as the Young Street District near the Halifax Forum (D'Silva 2024, Hurley 2024, Ryan 2024) and further afield at Exhibition Park, along with smaller developments in the city's south end. Densification proposals seem to be moving forward with little or no regard for the effects on the overall city landscape, the preservation of historically important buildings, local neighbourhoods, the need for more urban green space, and the city's overall appearance and attractiveness for both citizens and visiting tourists. Tourism includes tens of thousands of people coming each year on cruise ships and is of key importance to the local economy. As well, the ability for everyone to move around, on and off the Halifax peninsula, can be impeded by poorly located developments.

The current intensification to alleviate the housing crisis is being driven more by the availability of federal and provincial funds than by the results of thoughtful planning. The rush for the 77 million dollars from the federal government, the so-called Housing Accelerator funding, and dictates from the province for special development areas, have overridden planning initiatives over the last five years that have included some densification along bus transit corridors and been part of "the plan". Unfortunately, while young people are

not opposed to densification, this development boom has a cynical element in that it is not creating housing that anyone below having a six figure income can afford!

Improved passenger rail and ferry transportation (talked about for decades), would make it possible to spread new developments more evenly around the harbour, alleviating pressures on the city core and its main transportation routes. That would require genuine long-term planning and extended financial support. The studies required need input from scientists, including geologists and engineers, both local and from other cities such as Dublin, Ireland, where light commuter rail/trolleys have been successfully installed in the last thirty years (Anon. 2024). Halifax city planners appear to be too slow and uncommitted to initiate a truly enlightened housing development plan along with improved transit. Halifax used to be called "the smart city"! It is way past time to revisit and re-earn this epithet!

The second big issue to consider, one perhaps more directly related to NSIS's science mandate, is the current Conservative government's recent refusal to enact, i.e. proclaim, the provincial Coastal Protection Act. This decision was made after years of citizen discussions and passage of the Act with all party support in 2019 (CBC 2024, Hurley 2024, Wells 2024). The Act would have solved an obvious urgent need in Nova Scotia for coordinated coastal management in an era of climate change that brings increased sea level rise, more coastal erosion, and severe storms. There needs to be knowledgeable information available with respect to the locations of coastal infrastructure (e.g. people's homes) and avoidance of ineffective and highly damaging coastal hardening and infilling in areas prone to erosion. Downloading the responsibility of protecting the coasts and shorelines to the counties and municipalities will not work for many practical reasons, e.g. lack of resources and trained personnel for land-use planning and developing new regulations. The Act's cancellation and replacement with local action plans (typical bureaucratic stalling behaviour) is a major embarrassment for a province called "Canada's ocean playground". A more appropriate label might now be "Canada's mismanaged coast"! It is not too late for the government to change its mind and reverse the decision – the comprehensive Coastal Protection Act is needed now, without delay!

Both of these issues point to the interplay of politics, the potential for conflicts of interest, and the need for serious land use planning in

both urban and rural coastal areas of the province. Halifax's planned growth requires informed management, and wise and honest decisions. Coastal protection requires in-depth basic knowledge of climate change, ocean processes, and the applied science of coastal planning (including marine spatial planning and marine protection areas) for making coordinated and informed coastal policies and decisions. We as a society seem to be failing on both fronts. How did a smart city and province end up in this quandary? Is the system of governing simply inept or broken, or have local councillors and politicians been overtaken by self-interest, with little concern for the future? Where, when and how do we find and elect honest and unbiased decision makers?

In our view, the problem does not lie in the academic fields of urban development and coastal management. The basic principles in both fields are well established and expert advice is readily available. The problem is the lack of elected officials looking to the future with open eyes. Simply put, we cannot afford to be in this situation if we want our city and our coastlines to be habitable and safe.

Our Institute, the NSIS, surely has a role to navigate us towards an informed future for our city and our coasts. One solution may be to give serious attention to becoming "Honest Advocates" on such issues, defined as "contributing to decision-making in a purposeful, well-informed manner, doing social good without damaging the reputation of science" (Gregory *et al.* 2024). In our view, the city and province deserve nothing less.

We welcome your views and suggestions for the next steps to take as individuals and as an Institute. These and many other challenges (see previous recent PNSIS editorials) must be addressed as we are now well into the twenty-first century and are living in uncertain political, economic and environmental times. Sitting on the sidelines is not an option. Science has an important role in the public forum.

The breadth of the contributions to this Issue of the PNSIS is especially noteworthy and a sign of the variety of science conducted in our region. Two of the Commentaries deserve special mention, those penned by Don Gordon and Charles Schafer, both of whom sadly passed away while preparing their articles, a testament to their dedication to their science - oceanography. We dedicate this issue to them; they are an inspiration to us all.

The papers by Roger Marsters and Don Gordon are on ocean research carried out from two famous ships with a connection to Halifax, the HMS *Challenger*, visiting the port from England in 1873, and the CSS/CCGS *Hudso*n that conducted marine research for Canada from 1963-2022. An account of the Challenger's visit was published that year in our Proceedings (W. Gossip, "The Challenger Scientific Expedition Visit to Halifax," *Transactions of the Nova Scotian Institute of Science* 3 (1873), 335-337). This underlines the value and importance of the Proceedings now being available on-line and searchable. The account of the Hudson's work reflects Don Gordon's unique knowledge of that ships' many cruises and its accomplishments. One hopes that in 100 years time, people will be able to retrieve accounts of the work of both ships and wonder about the technical advancements so important to our understanding of the ocean.

We thank all three authors, Marsters, Gordon and Schafer, for their most interesting and informed Commentaries.

Acknowledgements We thank Patricia Manuel and Andrew Horn for their reviews of this article during preparation. Again, we dedicate this PNSIS Issue to two of our authors, Drs. Donald C. Gordon and Charles T. Schafer, both outstanding ocean scientists who sadly passed away recently while their papers were in press; their dedication to science while retired is an example and inspiration to us all.

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HMS *CHALLENGER*, NOVA SCOTIA, AND THE MARITIME WORLD

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The year 2023 marked one-hundred and fifty years since HMS *Challenger*'s visit to Nova Scotia during its landmark four-year circumnavigation and study of the deep ocean. The expedition's anniversary has been marked with commemorations, conferences and assessments of its work and legacies.[1] The passage of time offers new contexts in which to examine the expedition's experiences in Nova Scotia as well and, less obviously, how the province, it's geography and history, helped prepare the British state to conduct scientific research on a global scale.

Challenger's first view of Nova Scotia on May 9th, 1873, was a strangely distorted one. Coming in off the deep ocean, Fata Morgana mirages warped and etherealized the coastal landscape. Granite barrens rose free of the water, resting suspended in air above themselves. Rocks and islands stretched vertically into tall, narrow towers. Ships' tracks across the sky inverted those in the sea below.[2]

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[1] In November 2023 Royal Museums Greenwich, in association with the *Challenger* Society for Marine Science, University College London, and the British Society for the History of Science, held its Beyond the Ocean's Depths: *Revisiting the Challenger Expedition (1872-1876) Interdisciplinary Conference*: https://www.rmg.co.uk/whats-on/national-maritime-museum/beyond-oceans-depths-revisiting-challenger-expedition-1872-1876; in 2022 London's Natural History Museum hosted the *Challenger 150* conference: https://www.challenger-society.org.uk/Challenger_conference_2022. Recent studies of the expedition include Erika Jones, *The Challenger Expedition: Exploring the Ocean's Depths* (London: Royal Museums Greenwich, 2022) and Doug Macdougall, *Endless Novelties of Extraordinary Interest: The Voyage of H.M.S. Challenger and the Birth of Modern Oceanography* (New Haven: Yale UP, 2019); reviewed by Eric Mills in PNSIS 53:1 (2023), 147-150.

[2] Several of Challenger's staff and crew recalled strange optical effects in the Halifax approaches; most vividly, expedition artist J.J. Wild. See John James Wild, At Anchor: A Narrative of Experiences Afloat and Ashore during the *Voyage of H.M.S. Challenger from 1872 to 1876* (London: Marcus Ward, 1878), 28-30. One of Challenger's officers, Herbert Swire, was particularly attentive to the ways in which Halifax formed a link in growing maritime technological networks: Herbert Swire, *The Voyage of the*

Passing Prospect, south of Halifax, one officer noted where the overturned hull of the White Star liner SS *Atlantic* lay wedged in granite, victims of its wreck a month earlier entombed within. They passed a cable ship, servicing new telegraph cables carrying coded information deep underwater offshore. *Challenger*'s crew acknowledged the salutes of shore batteries, whose overlapping arcs of fire made contemporary Halifax a formidable redoubt of British power. Finally, the ship came alongside at the Naval Yard on the harbour Narrows, close by the Mi'kmaw village of Turtle Grove on the opposite shore.[3]

Arriving in Nova Scotia expedition artist John James Wild noted "We were now in a land of granite and pine forests."[4] As a naval station Halifax was familiar to many of *Challenger*'s crew. The civilian staff, however, were struck by contrasts between cozy (or dingy) provincial town and the barren or wooded landscapes surrounding it. The ship's cabins were soon perfumed with mayflowers (*Epigaea repens*) picked by welcoming townspeople. Officers dined with British regiments stationed at Wellington Barracks, north of the Naval Yard. *Challenger*'s naturalists presented specimens dredged from the deep ocean to Dr. David Honeyman of the Provincial Museum.

Footnote 2 cont'd

Challenger: A Personal Narrative of the Historic Circumnavigation of the Globe in the Years 1872-1876 (London: Golden Cockerell Press, 1938), 39-44.

[3] While Mi'kmaw people remained very much present and visible in the Nova Scotian population in 1873, the preceding century saw rights protected by the 18th-century Peace and Friendship Treaties fall into abeyance. With the transfer of responsibility for relations with Indigenous nations to the Canadian federal government after Confederation, Mi'kmaw people became subject to the Indian Act (1876) and other prescriptive legislation, further constraining their rights and activities. In 1872, the Naval Yard's Imperial landscape and the adjacent Indigenous landscape at Turtle Grove were further linked to the continental interior, as the Intercolonial Railway (later part of the Canadian National system) established its eastern terminus at Richmond, on the Halifax Harbour Narrows. For an overview of Halifax's integration into maritime and continental networks of exchange, and for the spatial dispossession of Mi'kmaw communities in the region, see Judith Fingard, Janet Guildford and David Sutherland, *Halifax: The First 100 Years* (Halifax: Formac, 1999). See also Jacob Remes, "Mi'kmaq in the Halifax Explosion of 1917: Leadership, Transience, and the Struggle for Land Rights,". Ethnohistory 61:3 (2014), 445-466; James D. Frost, "Halifax: The Wharf of the Dominion, 1867-1914," *Journal of the Royal Nova Scotia Historical Society* 8 (2005), 35-48; Jennifer Burke, "Turtle Grove: Dartmouth's Lost Mi'kmaq Community," in Alan Ruffman and Colin Howell eds., *Ground Zero: A Reassessment of the 1917 Explosion in Halifax Harbour* (Halifax: Gorsebrook Institute/Nimbus, 1994), 45-53.

[4] John James Wild, *At Anchor: A Narrative of Experiences Afloat and Ashore during the Voyage of H.M.S. Challenger from 1872 to 1876* (London: Marcus Ward, 1878), 28.

Fig 1 HMS *Challenger* at St. Thomas, West Indies, March 1873. See Eileen V. Brunton, *The Challenger Expedition, 1872-1876: A Visual Index* (London: Natural History Museum, 1994), no. 90. Nova Scotia Museum, Marine History Collection, MP28.70.6 [cropped].

Shore excursions included pilgrimages to Prince's Lodge, the ruined estate of Edward, Duke of Kent, who was Queen Victoria's father and former Commander-in-Chief of British Forces in North America. Behind an unpromising façade Halifax hosted a lively social and intellectual life.[5]

The *Challenger* Expedition (Figs 1-3) emblematizes how a complex of marine technologies related to steamships, submarine cables, hydrographic surveying helped to extend British empire globally during the nineteenth century.[6] Nova Scotia and Mi'kma'ki were pressed early into this empire: there were few places as robustly connected overseas, physically and culturally, as were Great Britain and Nova Scotia in 1873.

[5] *Challenger* staff and crew's reflections on Halifax were shared in several published voyage accounts; these, alongside Haligonians' experiences of Challenger's visit, are examined in Eric Mills, "H.M.S. *Challenger*, Halifax, and the Reverend Dr. Honeyman," Dalhousie Review 53:3 (1973), 529-545; Derek S. Davis, *Notes on a Collection of Specimens Made by the Challenger Expedition 1873* (Halifax: Nova Scotia Museum, 1973); Eric Mills ed., *One Hundred Years of Oceanography: Essays Commemorating the Visit of H.M.S. Challenger to Halifax, May 9-19, 1873* (Halifax: Dalhousie University/Nova Scotia Museum, 1975). The *Challenger* specimens are now in the collection of the Nova Scotia Museum, Halifax. For Prince's Lodge as a site of British imperial pilgrimage, see Sharon Ingalls and Wayne Ingalls, *Sweet Suburb: A History of Prince's Lodge, Birch Cove and Rockingham* (Tantallon, NS: Glen Margaret, 2010), chapter 9, "Prince's Lodge: Romantic Grounds".

[6] These themes and connections are examined in detail in Erika Jones, *The Challenger Expedition: Exploring the Ocean's Depths* (London: Royal Museums Greenwich, 2022).

Challenger rested alongside in a Naval Yard that was commissioned in 1759, ten years after British military forces and settlers occupied a large tract on the shore of Kjipuktuk, in Mi'kma'ki, and established the town of Halifax. The town became a node in maritime networks—military, social, commercial, scientific—linking Europe, Africa, the Caribbean, the Americas, and ultimately the entire world, into closer relationships. Established and developed as a forward base for the projection of military power around the North Atlantic (Fig 4), Halifax has since maintained the social and physical infrastructure necessary to direct force across oceans in times of war. The harbour was important in the Seven Years War and essential during the American Revolution, as it was again during the twentieth century.[7]

Among those drawn to Halifax by these maritime networks were individuals who prepared the way for the *Challenger* expedition by yoking science and engineering to the service of Britain's overseas expansion. In Halifax during the winter of 1758/1759, for example, army engineer Samuel Holland taught sailing master James Cook techniques of trigonometrical survey, skills that Cook employed on his world-altering circumnavigations. The Nova Scotia-based cartographer J.F.W. Des Barres' 1777 *Atlantic Neptune* maine atlas drew on the surveys of Holland and others to create the most comprehensive representation of Western Atlantic to that date, including lines of soundings run to the edge of the continental shelf.[8]

[7] To appreciate the shifts of British imperial and Mi'kmaw power in 18th- and 19th-century Mi'kma'ki/Nova Scotia see John Reid, "Empire, the Maritime Colonies, and the Supplanting of Mi'kma'ki/Wulstukwik, 1780-1820," *Acadiensis* 38:2 (2009), 78-97; John Reid and Emerson Baker, "Amerindian Power in the Early Modern Northeast: A Reappraisal," William and Mary Quarterly 3rd series, 61 (2004), 77-106. See also Jeffers Lennox, *Homelands and Empires: Indigenous Spaces, Imperial Fictions, and Competition for Territory in Northeastern North America, 1690-1763* (Toronto: University of Toronto Press, 2017), and Thomas Peace, *The Slow Rush of Colonization: Spaces of Power in the Maritime Peninsula, 1680-1790* (Vancouver: UBC Press, 2023). For an understanding of the navy and settler Halifax's role in this, see Julian Gwyn, *Ashore and Afloat: The British Navy and the Halifax Naval Yard before 1820* (Ottawa: University of Ottawa Press, 2004), and *Frigates and Foremasts: The North American Squadron in Nova Scotian Waters, 1745-1815* (Vancouver: UBC Press, 2003). Nova Scotia's position in 18th- and 19th-century networks of maritime military, economic and cultural exchange is the subject of a growing literature; see Jerry Bannister, "Atlantic Canada in an Atlantic World? Northeastern North America in the Long 18th Century," *Acadiensis* 43:2 (2014), 3-30.

[8] The progress and significance of post-Seven Years' War surveys in Nova Scotia is analysed by Stephen J. Hornsby in *Surveyors of Empire: Samuel Holland, J.F.W. Des Barres, and the Making of the Atlantic Neptune* (Montreal: McGill-Queens UP, 2011).

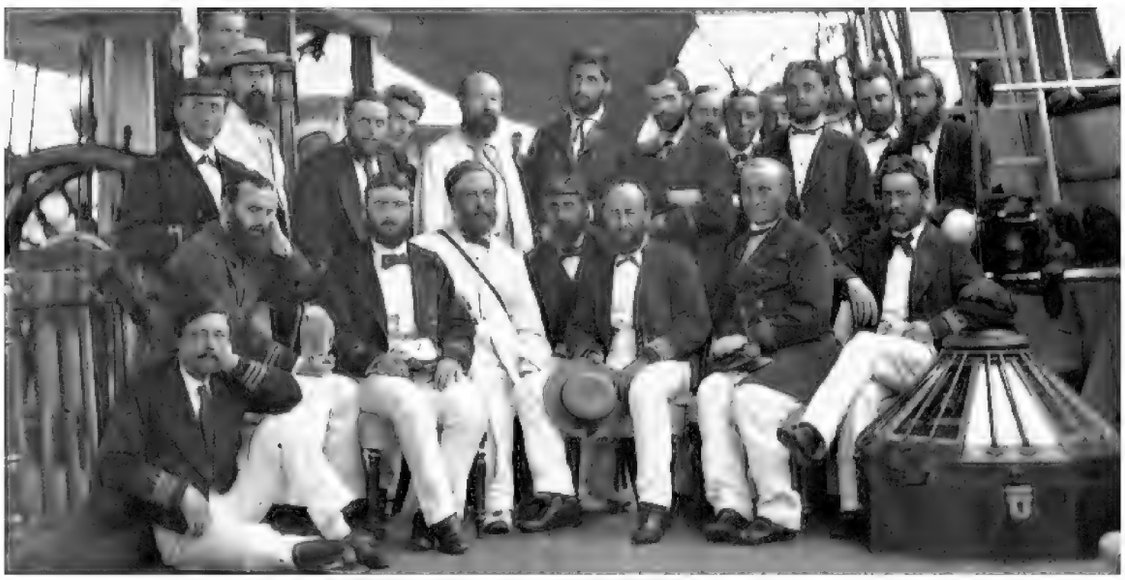

Fig 2 **Officers and civilian staff, HMS *Challenger*. At centre holding sennit hat is Captain George Nares; to Nares' right in white is the expedition's chief scientist, Charles Wyville Thomson. Also present are Rupert von Willemoes-Suhm, Herbert Swire, and John James Wild. See Eileen V. Brunton, *The Challenger Expedition, 1872-1876: A Visual Index* (London: Natural History Museum, 1994), no. 419. Nova Scotia Museum, Marine History Collection, MP28.70.19**

Fig 3 **HMS *Challenger's* band. See Eileen V. Brunton, *The Challenger Expedition, 1872-1876: A Visual Index* (London: Natural History Museum, 1994), no. 421. Nova Scotia Museum, Marine History Collection, MP28.70.24**

The British navy's embrace of science and engineering was formalized with the founding of the United Kingdom Hydrographic Office (UKHO) in 1795[9]. Over the next century, the UKHO's chart coverage grew in tandem with Britain's commercial and strategic interests.

[9] Recent analyses of the United Kingdom Hydrographic Office and its support for 19th-century science include Michael S. Reidy and Helen M. Rozwadowski, "The Spaces In Between: Science, Ocean, Empire," *Isis* 105:2 (2014), 338-352; Adrian Webb, "The Expansion of the British Hydrographic Administration, 1808-1829,"

Royal Navy hydrographic officers were in the vanguard of contemporary colonial expansion, and many were closely connected to Nova Scotia. Halifax-born Edward Belcher, for example, was dispatched in 1841 to survey Hong Kong harbour during the first Anglo-Chinese War; a decade later he oversaw the search for Sir John Franklin's lost expedition. One of Belcher's officers in the north was *Challenger*'s captain, George Nares.[10]

During the 19th century the United Kingdom Hydrographic Office became the most extensive scientific agency in the world, supporting research in hydrography and meteorology, tidal phenomena, geology, zoology and other disciplines. Under the direction of Edward Parry (who was well-connected in Nova Scotia) and Francis Beaufort, the UKHO developed wide-ranging natural-history competencies and relationships. One result was the Admiralty's 1849 *Manual of Scientific Enquiry*, with articles on tides by William Whewell, meteorology by John Herschel, botany by William Hooker, and geology by Charles Darwin.[11] This longstanding institutional commitment to inventory science—made mobile by the navy—was an important prerequisite to the *Challenger* voyage.

The geography and settlement history that vouchsafed Nova Scotia's role in transatlantic military activity likewise encouraged integration into growing commercial and scientific networks of the nineteenth-century maritime world. Samuel Cunard's interventions

Footnote 9 cont'd

(PhD thesis, University of Exeter, 2010); Helen M. Rozwadowski, *Fathoming the Ocean: The Discovery and Exploration of the Deep Sea* (Cambridge, MA: Harvard UP, 2008), 39-65;. Randolph Cock, "Sir Francis Beaufort and the Co-ordination of British Scientific Activity, 1829-55," (Ph.D. thesis, University of Cambridge, 2003). See also Archibald Day, *The Admiralty Hydrographic Service 1795-1919* (London: HMSO, 1967).

[10] Nares was Second Mate in HMS *Resolute* during Belcher's Franklin search expedition, 1852-1854. Trapped in ice, Belcher ordered that *Resolute* be abandoned. The crewless ship broke free and was recovered by American whalers; the United States government returned the ship to Great Britain. The White House 'Resolute Desk', carved from the ship's wood, commemorates this diplomatic exchange. See Trevor H. Levere, "Science in the Canadian Arctic, 1818-1876, from Sir John Ross to Sir George Strong Nares," *Arctic* 41:2 (1988), 127-137.

[11] Edited by John Herschel, the *Manual* prepared naval officers and others overseas to undertake systematic observations in a range of natural history disciplines; it remained in print for more than 50 years. The 1871 edition gives a good introduction to some of the many relations between the British navy and inventory science on the eve of the Challenger expedition. *A Manual of Scientific Enquiry: Prepared for Use by Officers in Her Majesty's Navy and Travellers in General* (London: HMSO, 1871).

Fig 4 Late-19th-century excursionists at Prince's Lodge, Halifax, with warships of the North America and West Indies Station at anchor in Bedford Basin. Nova Scotia Archives Photographic Collection. archives.novascotia.ca/photocollection/archives/?ID=7900

in transatlantic steamship operations joined locational advantage with entrepreneurial initiative resulting in wide-ranging consequences.[12] In 1841, just the second year of scheduled steamship service across the Atlantic, Cunard's *Acadia* brought geologist Charles Lyell to Halifax and to North America. On a short stopover he visited the Mechanics Institute, where he was shown "a large fossil tree filled with sandstone from strata containing coal in the interior". Lyell's growing interest in Nova Scotia in the Carboniferous Period contributed fundamentally to earth sciences in Canada, and to understanding of life in the late Paleozoic.[13]

Citizens of 19th-century Halifax were experts on the rituals of imperial power and turned out on May 19th, 1873, to cheer *Challenger* as the vessel resumed its circumnavigation (Fig 5). The band of HMS *Royal Alfred*, flagship of the North America and West Indies Station, played *Auld Lang Syne* as onlookers gathered along the harbourside.[14]

[12] Cunard envisioned transatlantic passenger service supported in part by subsidies for carrying the Royal Mail. Accomplishing this he was assisted by former Hydrographer of the Navy Edward Parry, whom he had known during the latter's service in Halifax; see John G. Langley, *Steam Lion: A Biography of Samuel Cunard* (Halifax: Nimbus, 2006), 85.

[13] Charles Lyell, *Travels in North America: With Geological Observations on the United States, Canada, and Nova Scotia* Volume 1 (London: John Murray, 1845), 3.

[14] Herbert Swire recorded this lively scene: as *Prince Alfred's* band played and Challenger's seamen aloft prepared to loosen sails, expedition scientist Rupert von Willemoes-Suhm sent a servant ashore to fetch a pair of boots, interrupting the staged departure. *Challenger* was unceremoniously fixed to a mooring buoy off the Naval Yard while boots and servant were retrieved: Herbert Swire, *The Voyage of the Challenger: A Personal Narrative of the Historic Circumnavigation of the Globe in the Years 1872-*

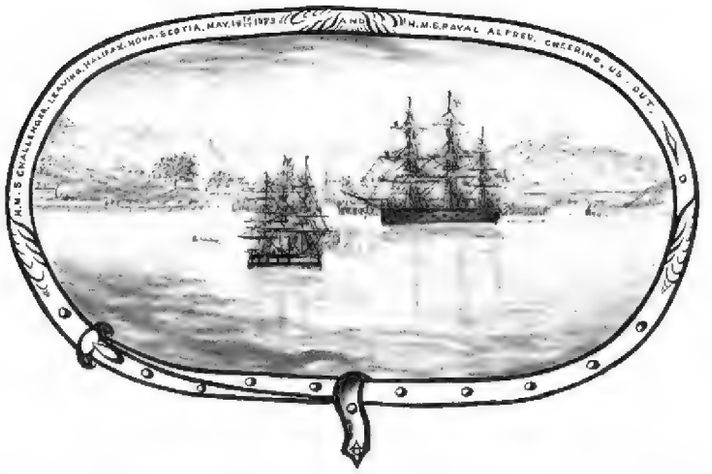

Fig 5 **Benjamin Shephard, HMS *Challenger* (right) leaving the Naval Yard. HMS *Royal Alfred* fires a parting salute as seamen prepare to loosen *Challenger's* sails. Minutes later the expedition was halted briefly, as a scientific staff member sent ashore to fetch his boots from a Halifax cobbler. See Benjamin Shephard, *Challenger Sketchbook: B. Shephard's Sketchbook of the H.M.S. Challenger Expedition 1872-1874* (Philadelphia: Philadelphia Maritime Museum, 1972). Nova Scotia Museum, Marine History Collection, MP28.70.1**

In the century-and-a-half since, the Halifax Harbour Narrows have changed beyond recognition. Still, today the Narrows is bounded on the south by the Canadian navy's Dockyard and on the north by the Bedford Institute of Oceanography; in between are a submarine-cable base, a shipyard building naval Arctic patrol vessels, and ancestral lands reclaimed by Millbrook First Nation in 2014. Rail and road networks skirt the maritime world here, linking ocean to continental interior. These persistent webs of scientific enquiry, military endeavour, of cultural and technological exchange—emblematized by *Challenger*'s visit—remain fundamental to life and opportunity in Mi'kma'ki and in Nova Scotia today.

HMS *Challenger* remained in Halifax for ten days in 1873, from 9 to 19 May. During that time the expedition's crew explored Nova Scotia, while Nova Scotians interested in science visited the ship and saw the wonders its naturalists had hauled up from the ocean floor. A lively account of the expedition's visit, with detailed descriptions of the ship and its discoveries, was published soon after in the Transactions of the Nova Scotian Institute of Science.[15] Through its 1872-1876

Footnote 14 cont'd

1876 (London: Golden Cockerell Press, 1938), 43. A promising young invertebrate zoologist, Willemoes-Suhm did not survive the expedition, dying at sea of erysipelas in September 1875.

circumnavigation, *Challenger* systematized investigation of the deep ocean, preparing the way for the modern discipline of oceanography. It shared novel marine specimens with scientific institutions worldwide, spurring research. Nova Scotia's continuing engagement with the deep ocean—via the navy, the Bedford Institute of Oceanography, the Nova Scotia Museum, the province's universities—follows in the wake of *Challenger*'s legacies.

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SHIP WITH A SOUL: A BRIEF HISTORY OF THE CANADIAN OCEANOGRAPHIC RESEARCH VESSEL CSS/CCGS *HUDSON* (1963-2022)

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After serving the Canadian oceanographic community with distinction for almost sixty years, the CSS/CCGS *Hudson* was recently retired. Her history and that of the Bedford Institute of Oceanography (BIO) were closely intertwined and she became a Canadian icon.

After World War II, there was a growing interest in oceanography around the world and it soon became a high priority of the Canadian federal government. In 1958, plans were announced by the Department of Mines and Technical Surveys (DMTS) to create BIO in Dartmouth, NS. Soon after, plans were also announced by DMTS to build a new oceanographic research vessel to be based at BIO. The driving force behind both these undertakings was Dr. William E. van Steenburgh, the Director-General of Science Services in DMTS.

The new vessel was designed by the marine engineering firm of Gilmore, German and Milne in Montreal with the capability of working anywhere in the world's oceans, in particular the North Atlantic and adjacent arctic waters. It was just the second scientific ship designed and built in Canada, the first being the hydrographic survey vessel CSS *Baffin* launched in 1956. She was built by Saint John Shipbuilding and Drydock, Ltd. in Saint John, NB at a cost of $7,500,000 and named after the early arctic explorer Henry Hudson (1565-1611). *Hudson* was launched in May 1963 and, after fitting out and sea trials, arrived at BIO in December 1963, a wonderful Christmas present for the recently opened institute. She was formally commissioned in February 1964 by the Honorable Paul Benedickson, Minister of DMTS.

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Upon arrival at BIO, she joined the existing fleet of research vessels which included CSS *Acadia,* CSS *Kapuskasing,* CSS *Baffin,* CSS *Maxwell* and CNAV *Sackville.* These were primarily hydrographic survey vessels and only the CNAV *Sackville*, operated by the Canadian Navy, was devoted to oceanographic research. At that time, BIO had only about fifty professional and technical staff belonging to the Canadian Hydrographic Service (CHS), the Atlantic Oceanographic Group (AOG) of the Fisheries Research Board (FRB) and the newly created Marine Sciences Branch (MSB). They were thrilled to have a brand-new state-of-the–art oceanographic research vessel available for their use. This was a period of unprecedented growth and both oceanographic staff and programs at BIO expanded rapidly over the ensuing decade.

Hudson was well-designed for her purpose. Her many features included a diesel electric propulsion system with two fixed blade propellers and bow thruster, an anti-roll system for stability, numerous wet and dry laboratories, open deck working areas fore and aft, numerous winches and cranes for handling all kinds of oceanographic equipment while underway and on station, a helicopter deck with hanger and hydrographic launches. Many improvements were made over the years as programs and equipment evolved. In addition, *Hudson* provided excellent accommodations for 28 scientific staff which allowed multidisciplinary programs to be carried out on a single cruise. She was also well-served over her entire career by excellent officers and crew. With the exception of some possible seasickness the first few days out, going to sea on *Hudson* was a pleasure for Canadian oceanographers.

It soon became evident that *Hudson* possessed outstanding sea kindliness and station keeping ability. She was able to operate effectively under extreme conditions, including in ice, and was ideally suited for winter work in the North Atlantic. This was partly due to the curved shape of her hull that afforded a more gentle passage over steep waves. With her extensive cruising range, she was capable of working anywhere in the world's oceans. She quickly developed the reputation of being one of the best oceanographic research vessels in the world and became the envy of other oceanographic institutions.

From 1963 to 1996, *Hudson* was operated by the BIO Ships Division under the responsibility of the science director. She was designated as the Canadian Science Ship (CSS) *Hudson* and painted white, the

traditional colour of oceanographic research vessels. She was manned by a single crew who were at sea most of the year between April and December. Then, as the result of a major DFO reorganization in 1996, the operation of *Hudson* was transferred to the Canadian Coast Guard and she became known as the Canadian Coast Guard Ship (CCGS) *Hudson.* She was subsequently painted red like other Coast Guard vessels but was still programed exclusively for oceanographic research. This transfer resulted in the introduction of the layday system for crewing. There were now two crews who served a month on followed by a month off which resulted in a significant boost to shipboard morale.

Although based at BIO, *Hudson* was used throughout her career by the entire Canadian oceanographic community. Principal non-BIO users included the DFO Maurice-Lamontagne Institute, the DFO Northwest Atlantic Fisheries Centre, Dalhousie University, McGill University and the University of Quebec. In addition, engineering staff from a number of Canadian R&D companies participated in numerous cruises. Many cruises also included international collaborators.

She spent an average of 167 days at sea each year and over her entire career carried out over 475 research cruises. It is estimated that she steamed approximately 1,565,000 nautical miles in support of science which is equivalent to sailing about 72 times around the world! While most of her work was done in the North Atlantic and Canadian Arctic, she also worked in the Caribbean Sea, South Atlantic, Antarctic and North and South Pacific. In her travels she made port calls in 18 other countries. During the Hudson 70 expedition, she became the first ship to circumnavigate the Americas and, in 1981, she circumnavigated North America which included traversing the Panama Canal. She made two successful passages through the fabled Northwest Passage, each by a different route. Except for her later years, she was very much an international traveler and informal ambassador for Canada (Fig 1a-f).

Over her lengthy career, *Hudson* supported research in all the major oceanographic disciplines in both the world's oceans and Canada's three oceans. Her work initially focused on understanding basic properties and processes of the ocean and underlying sediments and bedrock. In later years, it expanded as Canadian research priorities evolved to include more applied topics such as marine resource

development, the impacts of human activities on marine ecosystems, ocean monitoring and marine management.

Numerous marine engineering projects focused on testing at sea a wide range of new oceanographic equipment under development at BIO which when proven was extensively used on subsequent research cruises. Some of this equipment was subsequently transferred to industry for manufacturing and marketing.

Although designed primarily for oceanography, *Hudson* was also well suited for hydrography and conducted numerous hydrographic surveys in Canadian waters in support of navigational chart production. While traversing international waters, she routinely collected bathymetric data for the General Bathymetric Chart of the Oceans program (GEBCO). In more recent years she also was used to collect hydrographic data in support of extending Canadian territorial limits under the United Nations Convention on the Law of the Sea (UNCLOS).

Hudson was extensively used by geophysicists and geologists. Geophysical surveys of oceanic crust measuring bathymetry, gravity, magnetism and seismic properties were conducted in many locations but with particular focus on the Mid-Atlantic Ridge, off Atlantic Canada and in the eastern Arctic. The results had many applications including understanding the dynamics of plate tectonics and continental drift and helping to pave the way for the development of the Canadian offshore oil and gas industry. Geologists used *Hudson* to study sediments in environments ranging from coastal bays to abyssal depths using a wide variety of sampling and observational tools. This information was used to develop detailed maps of seabed properties and processes and contributed to increasing the understanding of geological history, sediment transport, seabed stability and geohazards. The results, including numerous maps, had many important applications and were used extensively by both industry and government.

Hudson was also extensively used by physical oceanographers to make fundamental contributions to the understanding of ocean circulation in both Canadian waters and the global ocean. Much of this work concentrated in the North Atlantic and the Labrador Sea which is an important site for deep water formation during the winter months. Early work used bathythermographs and Knudsen bottles with reversing thermometers to measure water properties at discrete

depths but these were later replaced by electronic instrumentation which measured conductivity and temperature continuously with depth (CTDs), thereby allowing the profiling of the entire water column. Over her career, *Hudson* was used to deploy and retrieve an extensive number of current meter moorings in both shallow and deep water, including the first such moorings in the Drake Passage. She made major contributions to the World Ocean Circulation Experiment (WOCE) and was used to deploy numerous profiling floats as part of the international Argo program. The results of this research had many important applications including global climate studies, development of offshore industries and fisheries management. *Hudson* was also used to study the properties and dynamics of sea ice.

Chemical oceanographers also made good use of *Hudson* to measure the concentration, distribution and dynamics of important chemicals in seawater and sediments in environments ranging from coastal waters to abyssal depths. These included hydrocarbons, nutrients, trace metals, organic carbon and components of the carbonate system. The results contributed to increasing the understanding of marine pollution and the impacts of human activities on ocean chemistry over time, including ocean acidification.

Hudson was also extensively used by biological oceanographers to study phytoplankton, zooplankton and benthic organisms in a wide variety of environments. A diverse array of sampling equipment was used to determine the species diversity, abundance, distribution and productivity of marine organisms. This work included the first biological oceanographic observations in the eastern arctic and the assessment of benthic communities in previously unstudied regions. Major contributions were made to international programs such as the Joint Global Ocean Flux Study (JGOFS). *Hudson* was also used to study the distribution of seabirds and whale migration. The results of this research had many applications, including understanding the effects of changes in ocean climate on marine ecosystems, fisheries and environmental management. Her work identifying sensitive seabed ecosystems played a major role in the creation of numerous protected areas closed to fishing activities such as The Gully Marine Protected Area (MPA), the coral closures in the Northeast Channel and the Stone Fence at the mouth of the Laurentian Channel and the closures in NAFO areas outside Canadian jurisdiction.

Numerous programs were carried out using *Hudson* to measure the impact of human activities on the ocean environment. One international

study examined the feasibility of disposing radioactive wastes in deep water sediments on the Sohm Abyssal Plain. The results clearly indicated that this was not advisable so the idea was dropped. Considerable effort was devoted to studying the fate and effects of operational wastes (drilling muds, cuttings and produced water) released from offshore oil and gas platforms on the Grand Banks and Sable Island Bank. These results were used to improve environmental monitoring programs and operational regulations. *Hudson* was also involved in carrying out large-scale field experiments with fishing vessels to determine the impacts of otter trawls and hydraulic clam dredges on benthic habitat and communities.

Beginning in 1998, *Hudson* was the principal vessel used in support of the Atlantic Zone Monitoring Program (AZMP), a major initiative involving the four Atlantic regions of DFO. Cruises collected physical, chemical and biological data along sixteen transects off Newfoundland and Labrador, Nova Scotia and in the Gulf of St. Lawrence to characterize oceanic variability at seasonal, interannual and decadal time scales and to establish relationships among the biological, chemical and physical variables. This extensive database, which continues to grow, is being used in many ways including assessing the impacts of climate change, validation of remote sensing data and oceanographic numerical models and the ecosystem management of fisheries. The results are reported in annual State of Ocean reports.

Hudson made many valuable contributions beyond serving as a platform for oceanographic research. While at sea, she was always on call for search and rescue missions and responding to environmental emergencies. In 1976, she rescued the crew of the *Cape Freels* who had taken to lifeboats after their fisheries patrol vessel caught fire and sank off Newfoundland. In 1979, she responded to the breakup of the oil tanker *Kurdistan* in the Cabot Strait. In 1982, she was the first to arrive on the scene when the *Ocean Ranger* capsized and sank in a severe storm on the Grand Banks. All hands were lost but she did recover some bodies and took them into St. John's. In 1987, *Hudson* rescued all 24 crew members of the MV *Skipper I*, a large bulk-carrier which foundered off the Grand Banks in hurricane-force winds and took them into St. John's. Then, in 1988, *Hudson* found the burning wreckage of the *Athenian Venture*, a Greek oil tanker which exploded and broke into two off Cape Race, Newfoundland. A day-long search found only one body of the twenty-nine people believed

to be on board. In 1988 she was involved in conducting surveys at the crash site of Swiss Air Flight 111 off Peggy's Cove and, in 2006, she suffered considerable damage when steaming to assist a stranded sailing vessel under hurricane conditions on the Grand Banks.

Over her career, *Hudson* suffered several mishaps of her own. For example, there were engine room fires in 1966 and 1974 with the latter leaving her dead in the water for several hours in the Sargasso Sea off Bermuda. Severe winter weather in the Labrador Sea in 1976 resulted in heavy seas smashing some windows and flooding the officer's lounge. That same year she lost a propeller in Lancaster Sound and had to finish her program and limp home under half power. Perhaps the potentially most threatening incident occurred in 1993 when she collided with an iceberg in Kangelugsuuak Fjord on the east coast of Greenland and ruptured her hull. Fortunately, there was a Danish naval vessel with a helicopter and divers nearby which came to her rescue and escorted her safely to Iceland for repairs.

On many occasions *Hudson* was open to the public. In 1967, she steamed to Montreal and welcomed over 20,000 visitors in just one week at Expo 67. She was frequently opened for public tours when visiting foreign ports and was always a popular attraction at BIO open houses. In addition, she also hosted many distinguished visitors both at home and away, including a visit of The Right Honourable Roland Michener, the Governor-General of Canada, in 1968.

In the mid 1990s, it was well recognized that *Hudson* would not last forever and discussions began on obtaining a suitable successor. While some early consultations on vessel design had occurred, it was not until 2017 that plans were finally announced to build a new Offshore Oceanographic Science Vessel (OOSV) as part of Canada's National Ship Building Strategy. This vessel is now under construction in Vancouver, BC and expected to arrive at BIO about 2026. This new vessel, yet unnamed, has specifications very similar to *Hudson* but will have a quite different deck layout and be equipped with new features including a dynamic positioning system for station keeping and multibeam sounding systems. While she appears on paper to be a suitable successor, it remains to be seen how well she will perform at sea under adverse conditions.

Near the end of her career, *Hudson* suffered numerous breakdowns which reduced her sea time considerably and unfortunately disrupted important time series of data collection. She never got to sea in 2017

and 2019. Several refits were carried out to extend her lifetime until her successor was available. However, time ran out and in early 2022 the Coast Guard announced that *Hudson* would be retired. She returned to BIO for the last time in January, a farewell open house for crew and staff was held in May and a formal decommissioning ceremony took place in July. In December, she left BIO under tow for the last time, almost 59 years to the day after she first arrived from Saint John, NB, and temporarily tied up on the Halifax side of the Narrows. In 2023, *Hudson* left Halifax Harbour for the last time and was towed to the R.J. MacIsaac Construction Ltd. shipyard in Sheet Harbour for demolition. Until the new Offshore Oceanographic Science Vessel arrives, east coast oceanographic cruises will reply on other vessels in the Coast Guard fleet or commercial charters.

Her longevity of 59 years is quite exceptional for research vessel, three years longer than the venerable CSS *Acadia*. However, it falls short of the 76 years that RV *Atlantis* served the Woods Hole Oceanographic Institution and the Argentinian Navy.

In summary, due to her size, facilities, crew and sea kindliness, *Hudson* was an exceptional oceanographic vessel. She went where few research ships could go and could work safely under extreme conditions. As a result, she supported ground-breaking multidisciplinary research throughout the world's oceans. She was an important factor in making BIO one of the top oceanographic institutes in the world. She became the queen of the Canadian oceanographic fleet and an icon for BIO. Both scientists and crew became very attached to her. In retrospect, the initial investment in building *Hudson,* $7,500,000, has paid huge dividends for Canada. She will be sadly missed but a similar successor is on the horizon. Her legacy of Canadian oceanographic research has provided a fundamental understanding of the waters and seabed surrounding Canada like no other ship and which will serve as a benchmark for the future generation of studies. She will be a tough act to follow.

Acknowledgements I thank Dave McKeown and Joleen Gordon for reviewing this manuscript and offering suggestions for improvement.

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Fig 1a **The brand-new *Hudson* arriving at BIO in December 1963.**

Fig 1b ***Hudson*** **working in ice.**

Fig 1c **New colours after transfer to the Canadian Coast Guard.**

Fig 1d ***Hudson*** **studying a natural hydrocarbon seep in Scott Inlet, Baffin Island.**

Fig 1e ***Hudson*** **studying operational drilling wastes at Hibernia.**

Fig 1f ***Hudson*****'s final return to BIO in January 2022.**

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CAN PLANKTONIC FORAMINIFERA HELP TO IMPLEMENT THE NEW UNITED NATIONS HIGH SEAS TREATY?

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INTRODUCTION

After two decades of planning and negotiations, the United Nations (UN) announced the passage of the High Seas Treaty on March 4, 2023. The Treaty aims to protect biodiversity in international waters, and the UN believes it will enable the enhancement and management of the ocean's resilience by allowing for the creation of marine protected areas (i.e., safe havens for fish, plants, and other vulnerable species) and the so-called "area-based management tools." Its broad intent is to support billions of people worldwide who rely on the oceans for basic needs (Kim 2023). It has been demonstrated that maintaining biodiversity is one of the key pillars to maintaining oceans' trophic levels (ocean food chain); by extension, it implies a sustainable human food supply. However, the task of selecting appropriate measures of biodiversity that have utility for international ocean management issues will require further study. For example, Harris (2007) notes that "what we now regard as the normal state of the oceans has been severely perturbed by the removal of top predators." It is also equally important to assess modification caused by unintended introduction of alien species, open ocean aquaculture, range of pharmaceuticals, anthropogenic chemicals, etc.

Consequently, these commercially valuable species are only of limited value in assessing contemporary ocean biodiversity patterns and trends. Harris (2007) further argues that "in a self-organized world where patterns arise from internal interactions, knowledge of biodiversity patterns alone is insufficient to explain what is occurring at any given time" and is an insufficient predictor of impending

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change. However, there is a light at the end of the tunnel, suggesting that assessing planktonic Foraminifera diversity may be able to overcome some of the weaknesses of the above argument and given their worldwide distributions and their preservation as a proxy for paleoenvironmental and paleoclimate indicators in ocean sediments (Yamasaki *et al.* 2022, Zeng *et al.* 2023).

The High Seas Treaty's overall mission reminded us of one planktonic Foraminifera study carried out during the Tahiti to Vancouver leg of the Hudson 70 expedition (Banerji *et al.* 1971). The entire associated unpublished 81 pages-long Bedford Institute of Oceanography (BIO) Internal Report (IR) of that leg is being reformatted for publication using the Natural Resources Canada Open File GEOSCAN reporting system. We have summarized some key observations below to widen the accessibility to broader readers and highlight the importance of planktonic Foraminifera in understanding diversity. This report describes the spatial abundance and diversity pattern of 30 planktonic Foraminifera species, within 10 genera, in three major Pacific Ocean water masses during the early summer of 1971 (Fig 1). These data are also placed with selected few subsequent studies from the equatorial and eastern Pacific Ocean to provide a broader context. As such, these data offer a potential foraminiferal biodiversity proxy signal against which future researchers can discern spatial and temporal trends in biodiversity. The value of planktonic Foraminifera as an environmental indicators is well known to link modern environmental parameters and reconstruct past environmental changes (Schiebel *et al.* 2018, Rashid *et al.* 2021, Chaabane *et al.* 2023). Most of these organisms are sensitive to environmental changes and are often restricted by a few limiting factors related to their associated water mass. Temperature, salinity, water depth, latitudinal variations, and inorganic and organic solutes in the surrounding water column are perhaps among the most important factors (Cf. Bé and Tolderlund 1971, Schiebel *et al.* 2018, Chaabane *et al.* 2023).

The Tahiti to Vancouver leg of the Hudson 70 expedition consisted of 12 sampling stations along the 150 West meridian from about 10°S to 55°N latitude (Fig 2), representing an 8334 km-long transect (Gordon 2021). Plankton tows were collected using a modified Benthos® Multiple Net Plankton Sampler fitted with 200-micron mesh nets. This type of sampler is particularly suitable for studying the vertical distribution of planktonic Foraminifera because samples

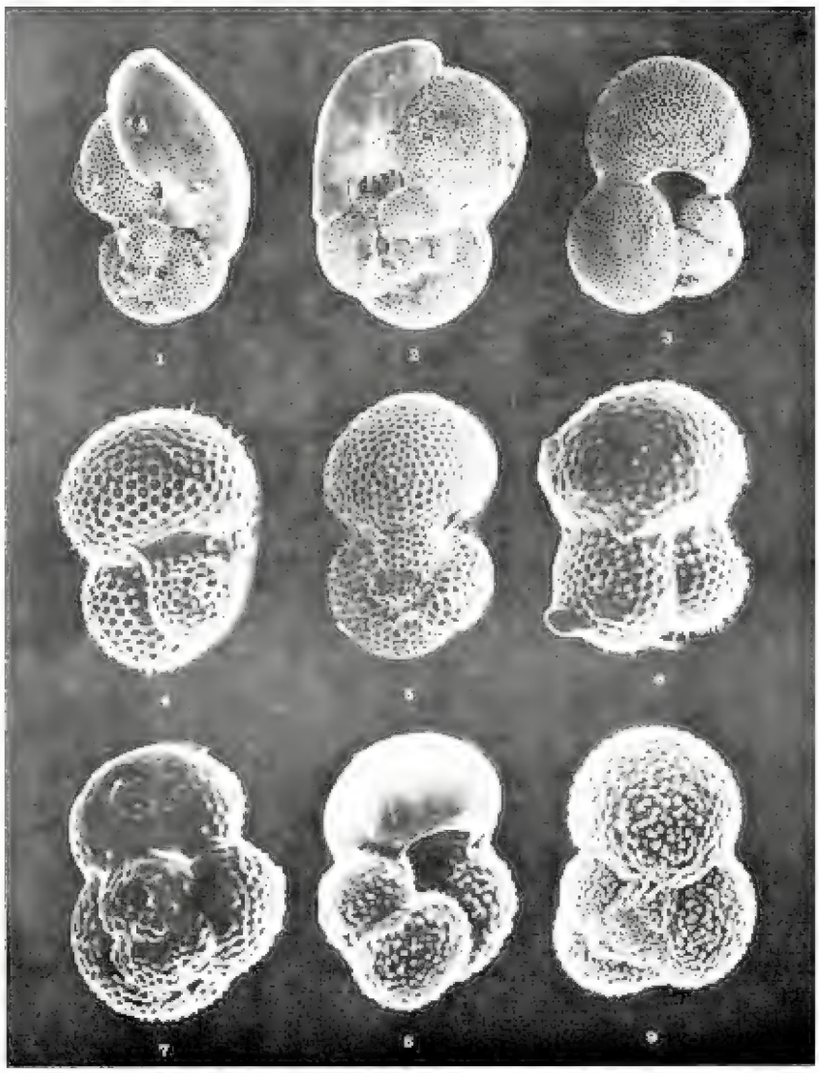
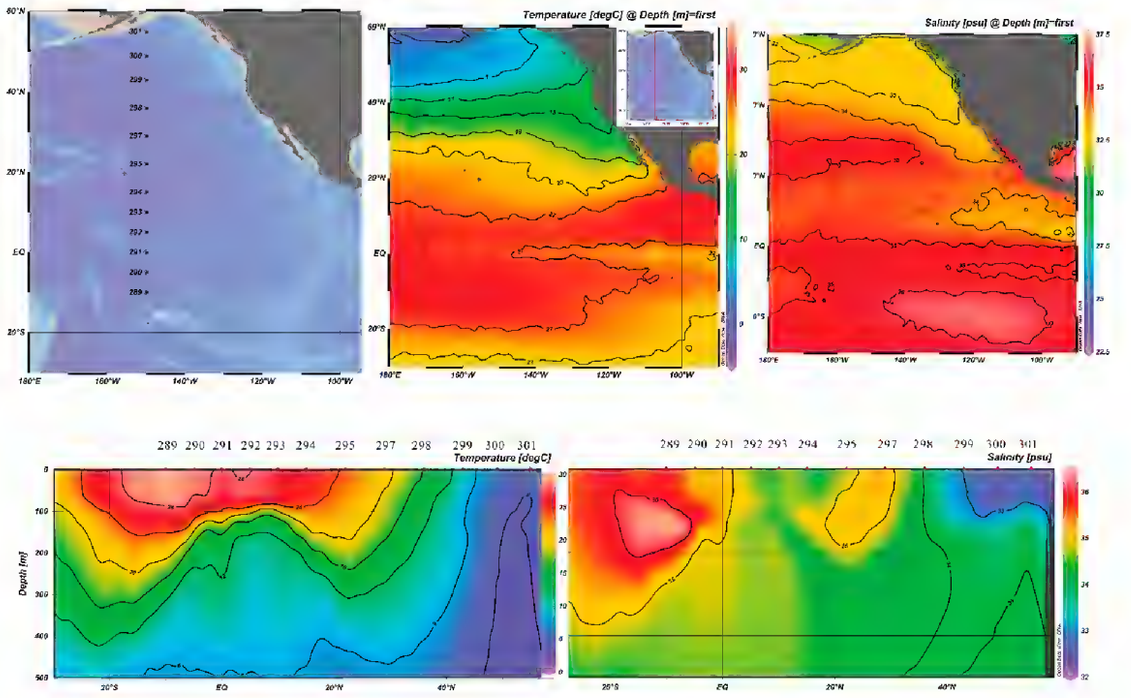


Fig 1 **Electron micrographs of two genera comprising three species of planktonic Foraminifera were collected during the Hudson 70 Tahiti to Vancouver leg. Photos 1-6 are of the genus *Globigerinoides*, and 7-9 feature various views of the genus *Globoquadrina*.**

can be obtained from specific depth ranges. The device was initially submerged to a depth of 25 metres and towed at a speed of about 1.5 knots for 15 minutes. Two additional tows were made during separate casts at 350 and 750-metre depths (Bé and Tolderlund 1971, Chaabane *et al.* 2023). The samples collected represent specimens resident in the 0-200, 200-500, and 500-1000 m water layers (Fig 3). For this regional survey, it was assumed that the concentration of planktonic Foraminifera remained approximately constant in the water layers sampled, not a patchy distribution, and that there was no appreciable daily change in the faunal population. The volume of water filtered through the nets was monitored using a Tsurumi-Seiki-Kosakusho flow meter® attached to one side of the triangular-shaped sampler frame. It was integrated with a Benthos® Model 1023 acoustic tele-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Salinity [psu]
Depth [m]

Fig 2 **Station locations for the Tahiti-Vancouver leg of the HUDSON 70 expedition. The 12 sampling stations covered three major Pacific Ocean water masses. The modern climatology suggests that mean May temperature and salinity produce two distinct isotherms and isopycnals. The bottom left panel illustrates one broad temperature cell with 24°C isotherm cropping out on both sides of the equator; however, two distinct cooler cells with 12°C isotherm are found at 300 m water depth. In contrast to the temperature, three isopycnals with 36, 35, and 33 psu cells were found within the stations covered by the survey.**

metering unit that signaled the water depth of the sampler and the closing and opening of nets during each deployment. On board, the samples were washed from each net and preserved in a 10% formalin solution buffered with hexamethylene tetramine.

PREVIOUS STUDIES

The first systematic study of living planktonic Foraminifera in the Pacific Ocean was conducted by Brady (1884) and Murray (1895). Bradshaw's (1959) classic work on the ecology of living planktonic Foraminifera in the north and equatorial Pacific Ocean represented a major breakthrough in a long gap of research quiescence. The author studied the Foraminifera from over 700 plankton samples collected in the north and equatorial Pacific. Twenty-seven species were identified and grouped into four biogeographic faunas, including cold, transitional, central, and equatorial. Their faunal boundaries coincided with hydrological divisions based on temperature and salinity data.

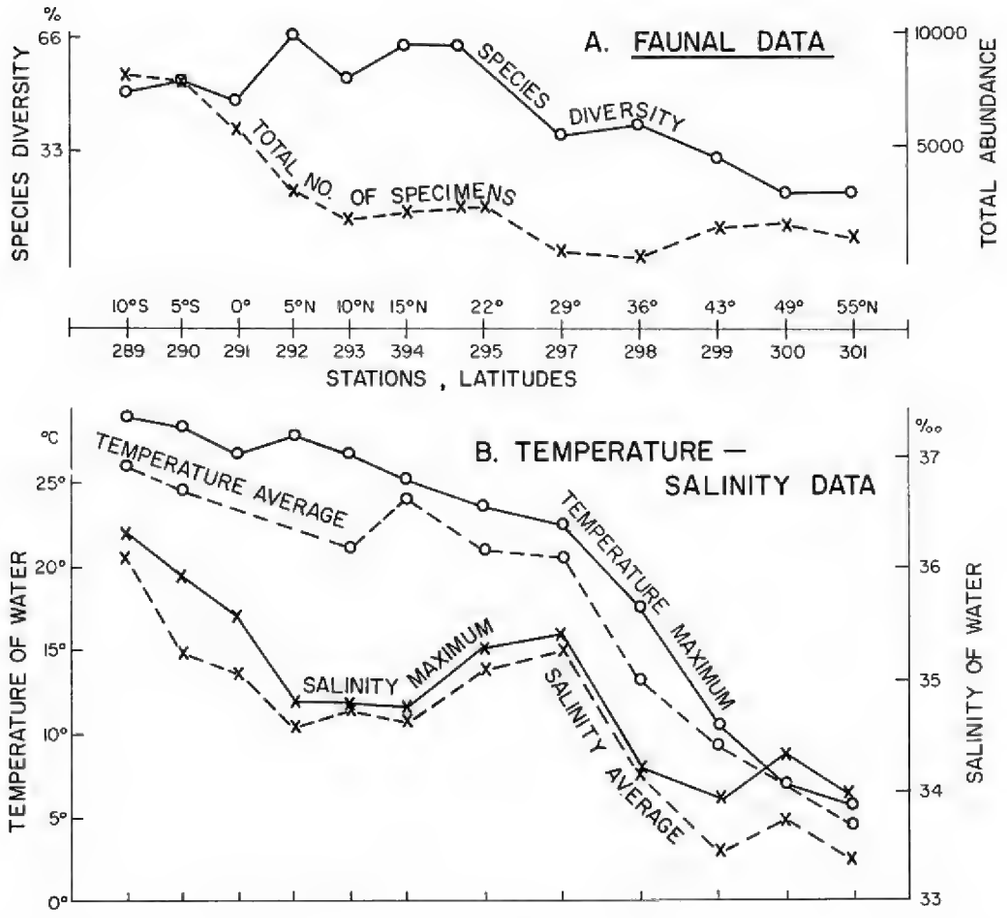

Fig 3 **Maximum and average temperature-salinity values of surface waters at various stations in relation to their respective foraminiferal species diversity and total number of specimens.**

One interesting observation by Bradshaw (op. cit.) was that the most abundant populations of planktonic Foraminifera per unit volume of water occurred in the subarctic water mass and at limited localities in the equatorial region. Parker (1960) extended Bradshaw's study towards the equator and South Pacific by noting the distributional patterns of 16 of the more common planktonic Foraminifera species. The author concluded that temperature may be more important than salinity in controlling the Foraminifera distribution. In a later publication, Parker (1962) discussed the systematics of all the planktonic species recorded from the South Pacific. In the following six decades, numerous subsequent studies built on the works of Bradshaw (1959) and Parker (1960) further updated and refined data about the seasonality of Foraminiferal blooms, temperature and salinity, genetic variations, and diversity from the eastern and equatorial Pacific (Schiebel *et al.*, 2018). Further, the increase in interest in understanding the

dynamics of surface currents and the evolution of the El-Nino southern oscillation (ENSO) led to the setting up of sediment traps in the eastern equatorial Pacific, particularly in Panama Basin, California Borderland, and Guaymas Basin in the Gulf of California (see Davis *et al.* 2019, for a review) were important.

SPECIFIC OBSERVATIONS

The entire equatorial and northern Pacific regions sampled during this study along the 150-meridian line may be divided into three water masses based on their physical and chemical properties. Water masses from south to north are designated as Southern, Central, and Northern, or Subarctic (Fig 2). The boundaries dividing these three water masses coincide approximately with latitude 32°N and latitude 46°N. The northernmost end of the southernmost boundaries could not be defined due to incomplete coverage. In any event, aII 29 plankton tows contained Foraminifera specimens. Fundamentally, the observed faunal composition is similar to that of Bradshaw (1959). Most of the species were found to be separated into restricted horizontal latitudinal zones and vertical depth categories. Four groups are recognized based on their associations with certain ranges of water temperature. A warm water species group thrives in the equatorial waters bounded by the 20°C isotherm (Yamasaki *et al.* 2022). Within this group, two faunal subgroups can be defined: 1). A Warm Tropical Species Subgroup exists around the equator to 15°N where the average sea surface temperature (SST) is approximately 25°C. Its indicator species include *Candeina nitida* (D'Orbigny), *Globigerina calida* (Parker), *Globigerinoides trilobus* (Reuss), *Globigerinoides ruber* (D'Orbigny), *Globoquadrina conglomerata* (Schwager), and *Globorotalia tumida* (Brady), 1). b somewhat cooler Warm Temperate Species Subgroup that thrives further north to latitude 30°N and coincides with an SST of 20°C. Species common to this subgroup include *Globorotalia inflata* (D'Orbigny) and *G. hirsuta* (D'Orbigny). Finally, a Cold Temperature Group in which six species thrive in this water mass including (in order of abundance): *Neogloboquadrina pachyderma* (Ehrenberg), *Globigerinita glutinata* (Egger), *Turborotaliata quinqueloba* (Natland), *Neogloboquadrina dutertrei* (D'Orbigny), *Globigerina bulloides* (D'Orbigny), and *Globorotalia inflata* (D'Oribgny).

Members of this Group thrive in waters from the equator to latitude 43°N, and their northern boundary coincides approximately with the ten °C isotherm. Last, there is a Cosmopolitan Species Group designated as the third group. *Globigerinita glutinata* (Egger) is the only true cosmopolitan species present in all the water masses of the northern and equatorial Pacific. At the same time, *Globorotalia inflata* (D'Orbigny) is present in the subsurface waters at most of the stations. Using seven-year sediment trap data from the Guaymas Basin of the Gulf of California almost five decades later, Davis *et al.* (2019) also concluded the annual presence of the *Globigerinita glutinata.* In comparison to this study, *G. inflata* appears to reflect dwelling in divergent water masses in the North Atlantic, e.g., it lives at the base of the seasonal thermocline (~100-200 m depth) in south of Iceland (Sahoo *et al.* 2022) while it is also found in the mixed-layer (~10 m) of subtropical waters associated with the warm North Atlantic Current (Schiebel *et al.* 2018, Zeng *et al.* 2023).

At most stations, three plankton tows were successfully retrieved and are designated here as Surface (S), Intermediate (M), and Deep (D). Broad groupings of faunal abundance at various depths and with respect to different water masses are evident. Since Hudson 70 data are derived from only one set of samples taken during the 1969 summer, these species do not lend themselves to broad generalizations for the entire year (see Schiebel *et al.* 2018 for a review). However, it may be stated that, for the 8334 km-long transect sampled, the abundance of planktonic Foraminifera decreases rapidly in the three successively deep-water levels (between the upper 200 m and the 500-1000 m levels) at an approximate abundance ratio of 5:1. This decrease in faunal abundance with increasing depth has been observed by various workers studying the characteristics of different oceanic water masses in various oceans (Kucera *et al.* 2005, Chaabane *et al.* 2023). Lohman (1920) was perhaps the first to give a quantitative estimation of the variations in the total abundance of specimens concerning depth in Atlantic waters. Subsequently, plankton tows and sediment traps data confirmed those findings. The author's data also show a pronounced decrease in specimens at depths > 200 metres. Bradshaw (op. cit.) determined that the highest concentrations of planktonic Foraminifera occurred between 6-30 metres in most tows and that the greatest decrease in number per M3 was noticed between 50-100 metres during his study of the northern Pacific. Hudson 70

survey observations in equatorial and north Pacific water masses revealed an almost uniform reduction in specimen abundance from the three depth categories sampled at most stations (Fig 4), consistent with the findings of numerous subsequent studies (Schiebel *et al.* 2018, Davis *et al.* 2019, Yamasaki *et al.* 2022). The depth limit of photosynthesis, in general, has been determined to be 120 metres in clear tropical waters, 40 metres in shelf waters, and 15 metres in turbid waters in temperate latitudes (Sigman and Hain 2012). It is well known that phytoplankton are one possible food source for planktonic Foraminifera (Kucera *et al.* 2005). Thus, the direct dependence on photosynthetic organisms as a food source may strongly control the bathymetric distribution of living planktonic Foraminifera.

Correlation analysis of the 29 Pacific planktonic Foraminifera samples from all depths indicated strong but almost equal effects of temperature and salinity on absolute abundance and species diversity (Banerji *et al.* 1971). Species diversity and specimen abundance correlate inversely with latitude and positively with temperature (maximum and average values) and average salinity. Nutrients (phosphates and nitrates) correlations are comparatively less significant; however, an inverse correlation of second order of importance was noted. Oxygen appears to be an insignificant factor; its presence in minor amounts is essential for organic metabolism.

Latitudinal variation in the composition of planktonic Foraminifera may most easily be explained using species diversity data. Species diversity (Ds) is defined as the number of species found in a sample and is generally expressed as:

$Ds = \frac{S}{TS} \cdot x100$, where Ds = diversity percent; S = number of foraminifera species observed at a particular station, and TS is the total number of species. Species diversity may be expressed either in actual numbers of species or as the relative percentage of species present in an assemblage. The Southern Water Mass includes that part of the equatorial warm-tropical to warm-temperature belt extending from south of the equator to latitude 30°N of this study. Stations within this water mass include 289, 290, 291, 292, 293, 294, 295, and 297 (Fig 2). Temperature and salinity values of its surface water vary from 22°C to 30°C and 34.6 to 36. 16 ‰, respectively. Species diversity varies from 50-66.70% in the surface waters, whereas the minimum diversity of 20% was noticed in the subsurface water of station 290 (at 05°S). All stations within this water mass

show a relatively high frequency of dominant warm water Foraminifera. These Foraminifera are divided into warm-tropical and warm-temperate species subgroups. The plot of species diversity concerning latitude illustrates a uniform decrease in diversity from the equator to the higher latitudes, as confirmed by numerous subsequent studies (Cf. Bé and Tolderlund 1971, Yamasaki *et al.* 2022). Certain unexplainable anomalies have been noted at a few stations. Plankton tows taken south of the equator (e.g., stations 289 and 290) are comparatively rich in foraminiferal specimens compared to the north. Warm-tropical species range from the equator to latitude 15°N, where the surface temperature is approximately 25°C. The species thriving in this area in order of their abundance are *Globigerinoides ruber* (D'Orbigny), *Globigerinoides toilobus trilobus* (Reuss), and *Globoquadrina conglomerata* (Schwager), which are relatively abundant, followed by *Globorotalia tumida* (Brady). The ratio of total specimens to species number decreases rapidly at northern stations. A Central water mass that lies between the Southern water and Northern or Subarctic water masses and includes a narrow zone bounded by 30°N and 45°N. Two stations (No. 298 and 299) were sampled to 900 metres depth on May 31 and June 2, 1970, and the maximum temperature and salinity were 17.6°C and 34.3‰, respectively. These two stations are located in a part of the Northern Pacific with intricate circulation patterns. Changes in the faunal assemblages are frequent due to the complexity of the circulation pattern, i.e., the mixing of the Southern warm water with the Northern cold water mass. Hence, the samples from this water mass have yielded dominantly warm and cold water species. Species diversity in this area is lower than that of Southern water and varies from 30 to 40% at all depths.

In general, faunal data of both the Southern and Subarctic waters are intermixed in the Central Water Mass so that the dimensions of the Central water mass vary depending upon the distance from the original faunal province and the degree of mixing. The faunal association within the Central Water Mass is characterized by the first appearance of *Neogloboquadrina pachyderma* (Ehrenberg) and the continued increase in *Globigerina bulloides* D'Orbigny specimens to the north. Mixing warm water from the south and cold water from the north has a pronounced effect on the distribution of a few less tolerant species in samples collected from two stations in the Central water mass. The Bering Strait separates the Northern or Subarctic

Water Mass from Arctic waters, beyond the collection coverage in 1971. The boundary separating it from the Central water mass runs approximately along latitude 45°N. Only two stations (No. 300 and 301) in the Central Water Mass were sampled on June 4 and 5, respectively. The maximum temperature and salinity of the water were 7.2°C and 34.35‰. The most interesting feature of the associated fauna in this area is the low but uniform value of 20% species diversity, which characterizes most of the plankton samples, and relatively higher specimen-to-species ratios compared to other areas. *Globorotalia cavernula* Bé has been recorded in amounts of up to 3% of the total fauna from the subsurface sample at station 301 (at 55°N). The change in the abundance of *Neogloboquadrina incompta* (Cifeli) living in Central water to *Neogloboquadrina pachyderma* (Ehrenberg) in subarctic water is a significant factor in delineating the boundary between these two water masses.

DISCUSSION

Scrutiny of the 81 pages of the BIO internal report (IR) demonstrates the somewhat "noisy" aspect of planktonic Foraminifera biodiversity when viewed at regional scales. However, the proxy indicator utility of these protozoans appears to offer a good starting point for addressing the High Seas Treaty ocean management mission for comparison to regional and seasonal changes. Nevertheless, it will likely require decades of inter-seasonal baseline monitoring along with biodiversity trends revealed in fossil assemblages preserved in seafloor sediments to reach the level of reliability needed for a regional-scale proxy indicator of changing environmental conditions of the earth's vast ocean space. For a start, a more practical approach might be to initially test the concept in just one of the four major oceans to confirm planktonic Foraminifera's suitability, reliability, and limitations as proxy indicators of natural and anthropogenic-driven environmental changes. Finally, we must never forget the teachings of Graham Harris (2007), whose writings repeatedly remind both researchers and the Treaty's management that the success of the High Seas Treaty approach "rests primarily on situations where the science is not in dispute, and where a strong lobby for political action exists." Harris argues further that although certain global prediction models can offer useful insights into future ocean environment trends, one

thing that they will probably not be able to do reliably for ocean environment change is to predict "sudden state shifts, hysteresis effects, and tipping points." For time scales on the order of months to years, measuring planktonic Foraminifera biodiversity trends may be the best and most cost-effective approach for detecting environmental impacts.

CONCLUSIONS

Five groups of living planktonic Foraminifera species were distinguished in the equatorial and northern Pacific. These groups include a warm-tropical (equator to 15°N), warm-temperate (up to 30°N), cold-temperate (up to 43°N), cold water (north of 43°N), and a cosmopolitan group. Factors such as temperature and nutrients appear to be most important in controlling the geographical limits of these groups. The population density of planktonic Foraminifera in Pacific waters decreases rapidly with increasing depth. The abundance ratio of specimens on the surface compared with subsurface waters during the period of this investigation was approximately 5:1. The decrease in the foraminiferal population with a depth of water is probably closely related to the degree of light penetration in seawater, which, in turn, controls phytoplankton distribution. There is a uniform decrease in species diversity from the equator to the higher latitudes in this part of the Pacific. A simple direct relationship seems to exist between the temperature and salinity of water and the absolute abundance and species diversity of Foraminifera populations in the Pacific.

The UN's High Seas Treaty proponent nations must recruit a worldwide cadre of biologically trained experts and affiliated institutions that can contribute spatial and temporal data germane to the Treaty's biodiversity-related objectives. As such, living planktonic Foraminifera monitoring appears to have a major role to play in the overall effort needed for cost-effective ocean space environment management decision-making that lies ahead.

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RAPID DROPS OF OCEAN TEMPERATURES IN SEVERAL SHALLOW BAYS IN NOVA SCOTIA DURING A RECENT COLD AIR OUTBREAK

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ABSTRACT

From February 3-5, 2023 Atlantic Canada experienced an extreme cold Arctic air outbreak with high winds that set many local meteorological records, including wind chills as low as -47°C. The impacts of the cold air outbreak on ocean temperatures and ice formation are investigated using predictions from the Coastal Ice-Ocean Prediction System for the East Coast of Canada (CIOPS-E), developed by Environment and Climate Change Canada. Observations from moorings further inform the predictions. The analysis suggests that during the event, several shallow bays and coastal areas in Nova Scotia experienced significant, abrupt temperature decreases ranging from 1.0 to 3.9°C. Overall cooling estimated by the model was 2.3°C for nearshore locations where observations recorded an average temperature decrease of 3.0°C. On the other hand, at individual sites the difference between observed and modelled cooling was up to 2.4°C. This difference can be attributed partly to the fact that the model does not adequately resolve the coastline features of some of the nearshore mooring sites.

In comparison, we also analyze another cold air outbreak that occurred on December 15-18, 2016, with wind chills as low as -37°C. The ocean temperatures changes associated with this earlier event saw decreases of 0.8 to 3.5°C, potentially contributing to an ongoing fish kill in St. Mary's Bay (near the mouth of the Bay of Fundy) at the time.

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Keywords: Ocean temperature, Cold air outbreak, Ocean forecasting, Shallow bays, Nova Scotia

INTRODUCTION

Cold air outbreaks (CAOs) are large-scale, low temperature atmospheric intrusions. While they often last for more than five days, a fast-moving CAO can be a short-lived event that can significantly impact a region. Atlantic Canada wintertime CAOs are usually caused by intrusions of cold Arctic air; their frequency and duration have decreased in the late 2010s compared to the late 1970s (Smith & Sheridan 2020).

On Feb. 3-5, 2023, Atlantic Canada experienced a fast-moving, short-lived CAO. Low temperatures combined with high winds brought extreme wind chill values at many locations. For example, at Halifax Stanfield International Airport the wind chill reached -43°C, while at Saint John, New Brunswick it was -47°C. Such extreme weather conditions can cause significant changes in ocean conditions such as a drop in ocean temperatures that could be stressful to marine life. Fish-kill events have been observed during CAOs on Okinawa-jima Island, Japan in 2023 (Gomez *et al.* 2024) and in Florida in January 1977 (Gilmore *et al.* 1978). Sudden intrusions of cold water have also resulted in a massive tilefish kill off the mid-Atlantic Bight immediately southwest of the Gulf of Maine (Marsh *et al.* 1999). In a news release, February 2022, Seaward Enterprises Association of Newfoundland and Labrador Inc. has attributed a large mackerel kill in December 2021 off the east coast of Newfoundland to cold water (fisherynation.com). St. John's weather records indicate a sustained period of average air temperature of -2.8°C (minimum -11.4°C) accompanied by average winds of 30 km/h (maximum 71 km/h) which could have been the cause of the ocean cooling; the average (minimum) wind chill was -11.4°C (-18°C) from Dec. 14 to 31. In Nova Scotia, another CAO in mid-December 2016 may have contributed to a significant fish kill event in St. Mary's Bay, however the evidence is inconclusive (Foley *et al.* 2019, Department of Fisheries and Oceans Canada 2017). (Note that wind chill, which depends on air temperature and wind speed, is an indicator of the potential for heat loss, and is used here as a reference for which people are generally familiar. The models used in this study explicitly estimate all

heat exchanges between the atmosphere and ocean as outlined in the references below.)

Given the potential impacts of rapid ocean cooling during intense CAOs, identifying the most threatened areas to such extreme events may be used to industry advantage, such as for aquaculture site selection. With operational ocean and weather predictions available, forecasting extreme events several days in advance could help industry to develop mitigation measures.

Here, we investigate the impacts of the February 2023 and December 2016 CAOs on ocean temperatures using both *in-situ* observations from moored instruments, and results from the high-resolution Coastal Ice Ocean Prediction System for the East Coast of Canada (CIOPS-E) ocean model (Paquin *et al.* 2021, 2022, 2024; see Fig 1 for model domain and bathymetry) obtained from Environment and Climate Change Canada (ECCC). Wind and air temperature observations from ECCC are used to quantify the timing and intensity of the CAOs over the region. The locations and magnitudes of significant water temperature changes are determined and their causes are discussed.

OCEAN MODEL AND OBSERVATIONS

We use both *in-situ* observations and model results to investigate the ocean temperature response to the CAOs. The observations are mainly from wharf-mounted instruments for the February 2023 event, and from both moorings and sensors deployed in lobster pots during the December 2016 CAO. The model and observations are complementary: the model provides broad scale coverage of ocean variables including ice; the coastal observation sites provide data for areas where the model does not resolve the topography well and have the potential to suggest improvements to the model.

CIOPS-E model

CIOPS-E has been run operationally at ECCC since 2021 (Paquin *et al.* 2021, 2022, 2024). The CIOPS-E system uses the Nucleus for European Modeling of the Ocean version 3.6 (NEMO, Madec *et al.* 2015) coupled to Los Alamos Community Ice CodE (CICE, Hunke 2001, Lipscomb *et al.* 2007, Hunke and Lipscomb 2008) to produce simulations of the ocean and sea ice conditions over the East Coast of Canada and the Gulf of St. Lawrence. Briefly, CIOPS-E delivers two main products: 1) a continuous simulation using spectral

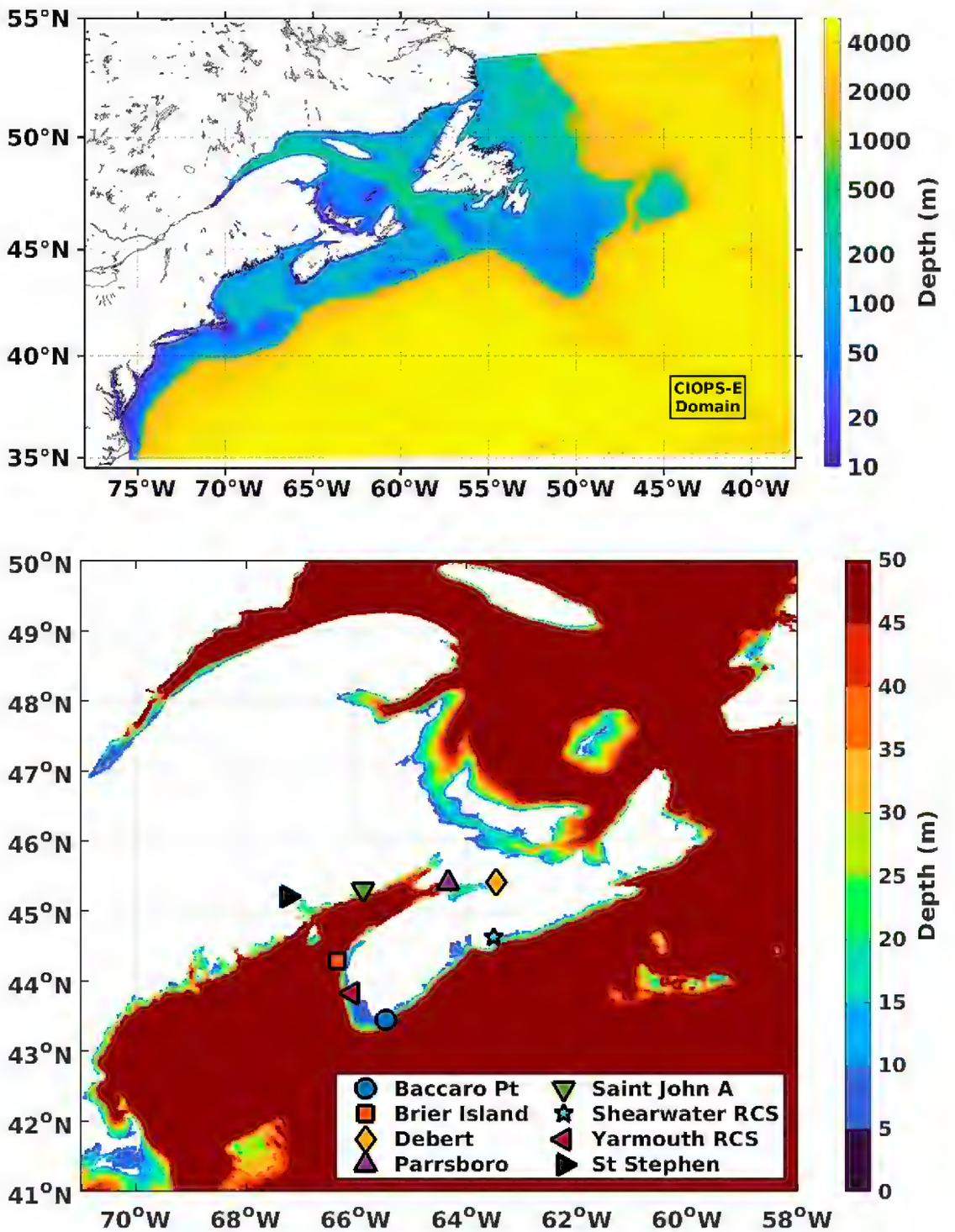

Fig 1 **CIOPS-E full-domain bathymetry (m, top) and zoomed-in area of interest (m, bottom), using different color scales to emphasize the shallow areas and bays. The bottom panel also shows ECCC weather stations adjacent to the coastal areas of Nova Scotia and New Brunswick used in this study.**

nudging, referred to as a "pseudo-analysis"; and 2) a short-term 48-hour forecast produced four times daily. The CIOPS-E horizontal resolution is approximately 2 km at the latitude of Nova Scotia. In the vertical, CIOPS-E concentrates 20 of its total 100 vertical levels in the first 30 m of the water column to better represent near-surface

ocean processes and heat exchanges. The minimum water depth is 7.5 m in the area around Nova Scotia and in the Bay of Fundy.

CIOPS-E solves the governing equations for ocean currents, sea level, temperature and salinity, and the formation, melting, movement and deformation of sea ice. The atmospheric forcing used to provide surface conditions to the ocean model comes from a combination of two Numerical Weather Predictions models, also running operationally at ECCC. Short-term forecasts from the High-Resolution Deterministic Prediction System (HRDPS, Mildbrandt *et al.* 2016) and the Global Deterministic Prediction System (GDPS, Gasset *et al.* 2019) are combined to provide continuous and coherent hourly forcing for the ocean model. The atmospheric forcing variables include near-surface wind, temperature and humidity, incoming radiative fluxes (solar and infrared), and freshwater fluxes from precipitation and climatological river runoffs. The main tidal constituents are imposed at the model lateral boundaries (elevation and transport), and propagation of the tides in the model domain interior is resolved explicitly. The non-tidal conditions for temperature, salinity, and ocean currents are also provided at the model open boundaries from ECCC's Regional Ice-Ocean Prediction System (RIOPS, Smith *et al.* 2021). To assure the consistency of the large-scale circulation in the pseudo-analysis, a spectral nudging method is used to correct CIOPS-E's three-dimensional temperature and salinity fields towards RIOPS' data-assimilative solution (i.e. constrained by *in-situ* and satellite observations). The spectral nudging method in CIOPS-E is applied only off the continental shelf to constrain the large-scale features, such as the Gulf Stream eddies and meanders. In our area of interest on the shelf, the CIOPS-E solution is not constrained, allowing the model to fully take advantage of CIOPS-E's high resolution. Detailed discussions on the model implementation can be found in Paquin *et al.* (2024). The pseudo-analysis simulation covers the period from November 2015 to present, therefore allowing comparison with observations for both CAOs (2016 & 2023).

Observations

In-situ temperature data, sampled hourly, were collected by moored instruments deployed in lobster traps on the ocean floor by the Fishermen and Scientists Research Society (FSRS, fsrsns.ca; December 2016 CAO only), and by instruments deployed and maintained at

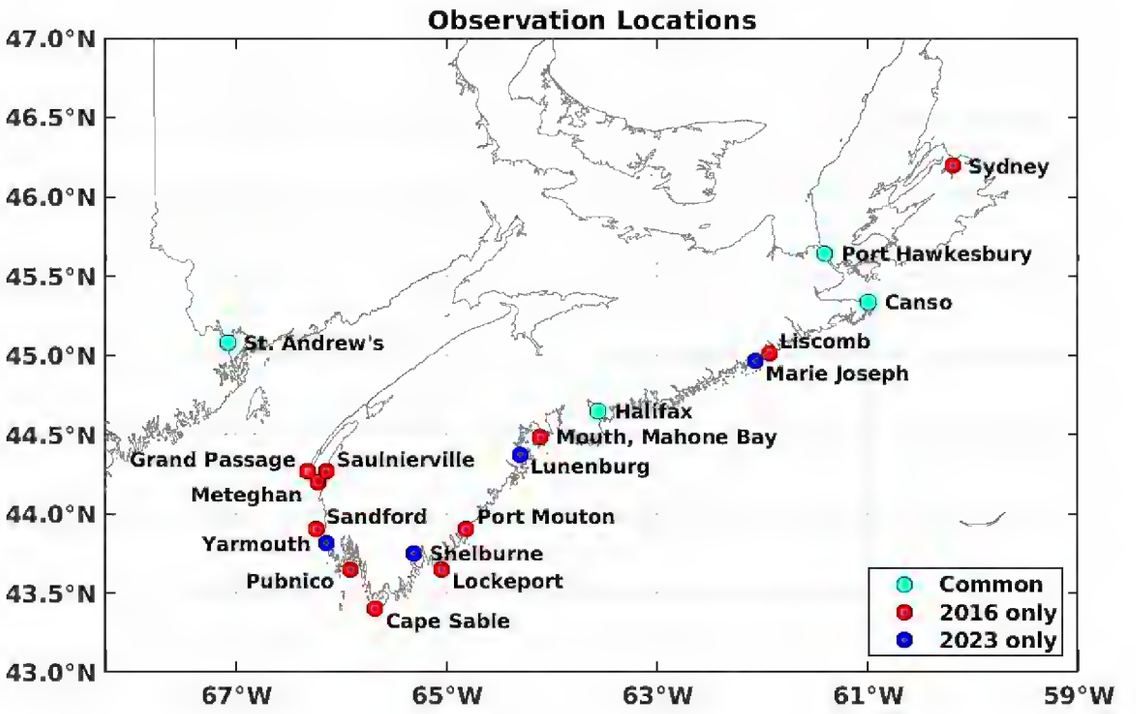

Fig 2 Ocean temperature observation sites for the 2016 (red) and 2023 (blue) CAOs, and the sites common to both events (cyan).

wharfs by the Bedford Institute of Oceanography (BIO), Department of Fisheries and Oceans (DFO) Canada, and St. Andrews Biological Station (StA), DFO (both CAOs), see Fig 2 for locations. Table 1 provides detailed information for each mooring (location, depth of deployment, type of deployment, and data collection agency). Sensors deployed in lobster pots measured sea-bottom temperature at that location, other sensors took measurements at the indicated depths.

For each instrument site, nearby model points were chosen for comparison. However, the detailed coastline at some sensor locations is not resolved by the model. In those cases, the nearest model point was chosen for comparison. This led to differences in depth (Model – Instrument) of ~+80 m to -16 m (Table 1). The names of the FSRS sites are taken from the nearest geographical location of note and do not necessarily indicate that the instrument was deployed at the exact location from which the name is taken, e.g., Lockeport.

FEBRUARY 2023 COLD AIR OUTBREAK

Meteorological conditions

For the CAO of Feb. 3-5, 2023, Fig 3 presents a map of predicted 1.5 m air temperatures and 10 m winds speeds from the HRDPS of the Canadian Meteorological Centre (Milbrandt *et al.* 2016) at the

Table 1 **Mooring site locations and characteristics for observations for the 2016 and 2023 CAOs. Also indicated are site bottom depths and temperature changes from model results and observations. Observation data sources are: St. Andrew's Biological Station (StA), DFO; Fishermen and Scientists Research Society (FSRS); Bedford Institute of Oceanography (BIO), DFO. StA and BIO sites were located at wharfs at the indicated depths, FSRS sites were deployed in lobster traps on the ocean floor.**

2016 Sites	Instrument Depth (m)	Bottom Depth (m)		ΔT (°C)		Source
		Obs.	Model	Obs.	Model	
St. Andrew's	2	< 10	24.6	1.7	1.3	StA
Grand Passage	7	7	12.8	1.4	2.0	FSRS
Saulnierville	17	17	10.8	1.2	2.5	FSRS
Meteghan	29	29	12.8	1.0	1.7	FSRS
Sandford	33	33	21.0	1.6	0.4	FSRS
Pubnico	18	18	7.3	2.5	2.5	FSRS
Cape Sable	26	26	8.9	1.8	6.3	FSRS
Lockeport	14	14	24.6	1.0	2.3	FSRS
Port Mouton	3	3	7.3	1.1	2.4	FSRS
Mouth, Mahone Bay	7	7	7.3	1.9	3.9	FSRS
Halifax	2	< 10	8.9	1.2	1.1	BIO
Liscomb	13	13	10.8	2.4	2.1	BIO
Canso	3	< 10	82.2	3.7	1.5	BIO
Port Hawkesbury A	1.5	< 10	10.8	3.1	1.2	BIO
Sydney	1.5	< 10	8.9	2.4	2.2	BIO
2023 Sites						
St. Andrew's	1	< 10	24.6	2.1	2.1	StA
Yarmouth	2	< 10	8.9	3.9	2.2	BIO
Shelburne	1	< 10	7.3	2.9	3.5	BIO
Lunenburg	5	< 10	7.3	3.8	3.2	BIO
Halifax	2	< 10	8.9	1.0	2.2	BIO
Marie Joseph	2	< 10	10.8	3.0	2.8	BIO
Canso	3	< 10	82.2	3.7	1.3	BIO
Port Hawkesbury B	3	< 10	10.8	3.5	1.1	BIO

peak of the event on Feb. 4, 12:00 AST (Atlantic Standard Time; unless noted, all times are in AST). The map illustrates the large geographical extent of the CAO, the coherence of the wind forcing, and air temperatures of about -16°C to -20°C in the area of interest.

Surface air temperature and wind-chill time series (top panel, Fig 4) from selected ECCC weather stations around the Bay of Fundy and Nova Scotia (bottom panel, Fig 1) give a timeline of events (ECCC 2023). The cold air reached stations in southern New Brunswick and Nova Scotia a few hours after Feb. 3, 00:00, with air temperatures returning to pre-outbreak values by the latter half of Feb. 5. The coldest temperatures were recorded in southern New Brunswick, the warmest in southwest Nova Scotia (SWNS). Although

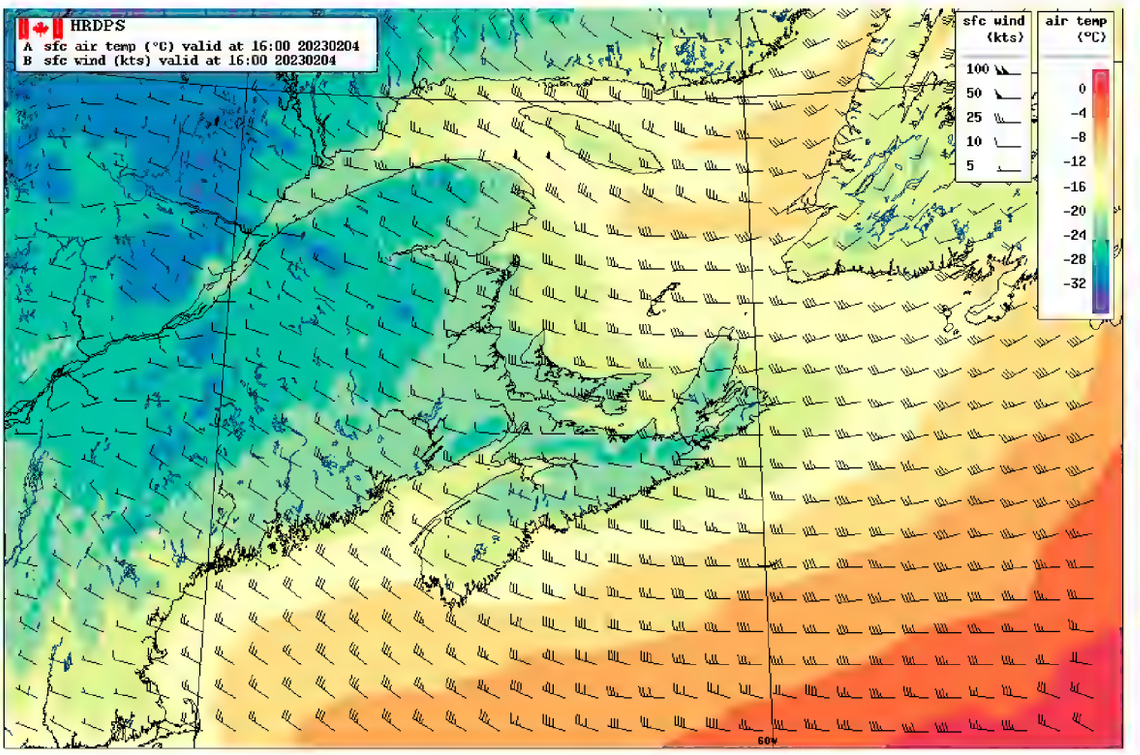

Fig 3 **HRDPS-predicted 1.5 m air temperatures (°C) and 10 m winds (kts, 1 kt = 1.852 km/h) on Feb. 4, 2023, 12:00 AST (16:00 UTC).**

hard to precisely define, as the timing is slightly different at each site, the grey-shaded areas in Fig 4 (and subsequent Figs) delimit the approximate temporal extent of the CAO based on air temperatures. The event begins at St. Stephen and propagates to the south-east, with Shearwater the last site affected. An analysis of correlations between the two sites shows Shearwater lagging St. Stephen by 4 h. Over this period, the average correlation among the air temperature series was 0.95 with a standard deviation of 0.04. During the event, the average temperature at the warmest site, Baccaro Point, was 8.8°C greater than that at St. Stephen and Saint John, the coldest sites. Air temperatures dropped from the range of +5 to -5°C to between -18 and -27°C in less than a day, and then returned to pre-outbreak temperatures by 1.5 days after the minimum.

Throughout the CAO, winds were predominately west-north-westerly (WNW), with pre-outbreak speeds of 5 to 20 km/h, which increased to peak values of 20 to 70 km/h around Feb. 4, 00:00 (middle and bottom panels, Fig 4). Winds then slackened to 0 to 10 km/h at around Feb. 5, 00:00. Some locations, such as the Yarmouth Reference Climate Station (RCS) then saw a slight re-intensification of wind speeds to 10 to 40 km/h, with a directional change to southwesterly for the last few hours of the CAO. The combined cold

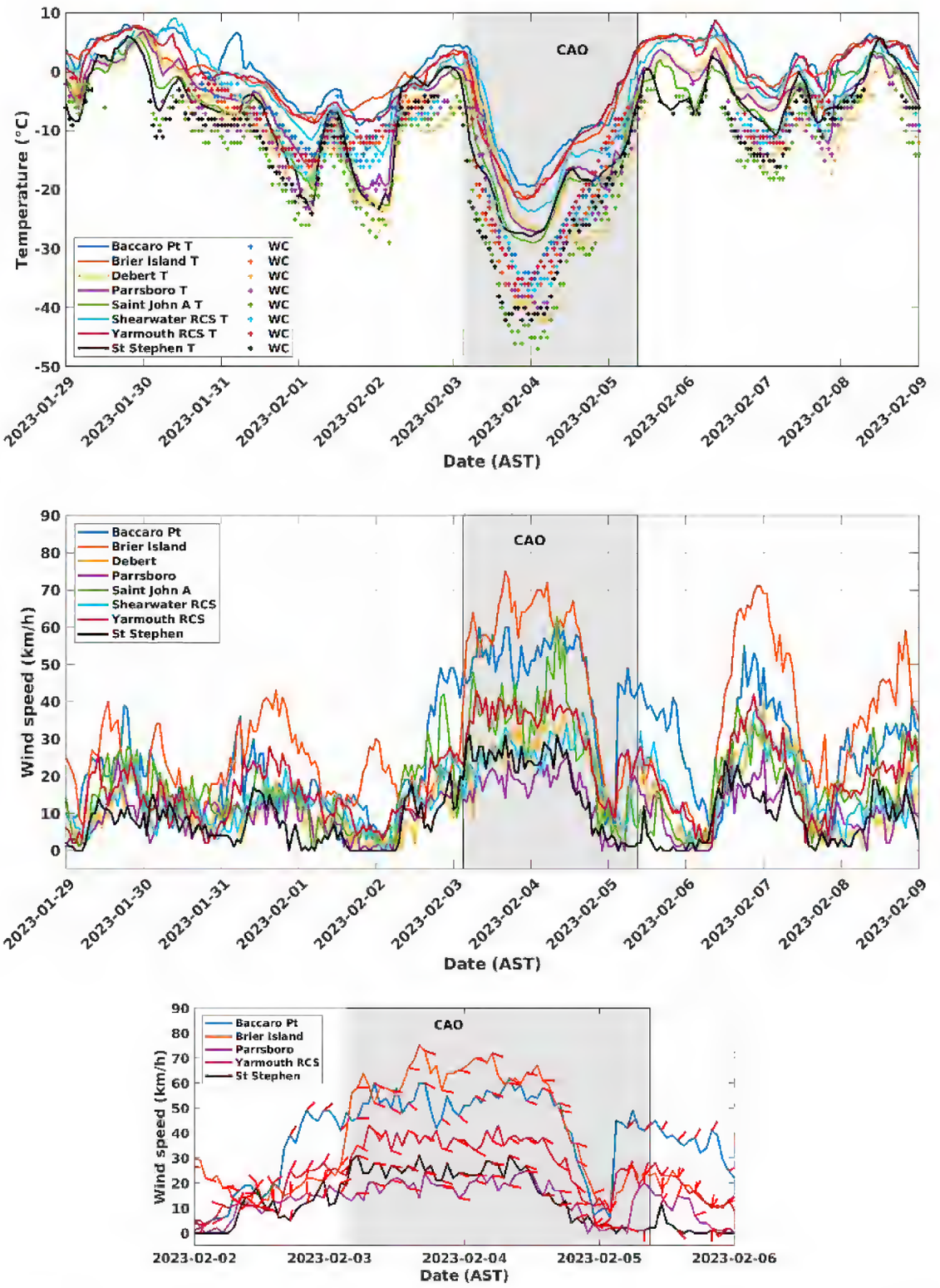

Fig 4 **Top panel: air temperatures (°C; solid lines) and wind chills (WC;°C; '+' symbol) as measured by the ECCC stations in Fig 1. Middle panel: wind speeds (km/h) at the same sites. Bottom panel: wind speed (solid lines) and 'to' directions (short red lines) for a shorter period around the CAO for select representative sites. Winds were generally to the east-southeast during February 3-5, 2023.**

air temperatures and wind speeds resulted in extreme wind chills ranging between -34 to -45°C on Feb. 4, 00:00 (top panel, Fig 4). The variation of wind chill during the CAO was very similar to the

air temperature series: correlations among sites were high, with an average of 0.89 ± 0.08; and, southern New Brunswick had the lowest average wind chill while WNS had the highest. The temporal evolution of the CAO is clearer for wind chill than temperature with the onset at St. Stephen, and the largest lag of 6 h at Shearwater.

The February 2023 CAO was an extreme event: for four hours a wind chill of -37°C was recorded at Shearwater RCS (solid red line, Fig 5); these were the lowest, hourly wind chills recorded at that location for all Februarys from 1994 through 2023. From Feb. 3, 21:00 to Feb. 4, 14:00 wind chill fell into the lowest 1% of 1993 to 2023 February values (lower red-dashed line, Fig 5), and air temperatures (solid blue line, Fig 5) were in the lower 1% from Feb. 3, 23:00 to Feb. 4, 12:00 (lower blue-dashed line, Fig 5). Significant heat loss from the ocean to the atmosphere would be expected for these conditions.

Model sea-surface temperature changes during the CAO

To identify areas of interest, we first analyse the broader-scale response of the ocean using model results. Fig 6 shows broad-scale maps of daily-averaged sea-surface temperature (SST) from CIOPS-E from before (Feb. 2) and after (Feb. 5) the CAO, and the difference between the two. The SST differences show that several bays and

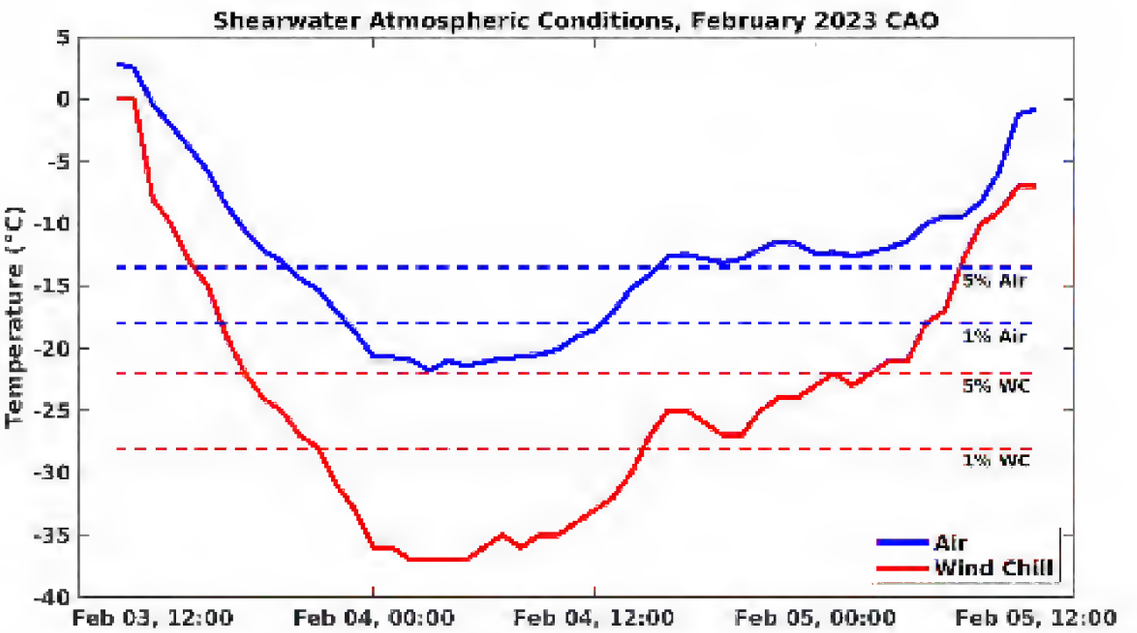

Fig 5 **Time series of air (blue solid) and wind chill (red solid) temperatures (°C) at Shearwater during the February 2023 CAO. The red and blue-dashed horizontal lines indicate the lower 1 and 5 percentile bins for all February hourly observations from 1994 to 2023 (12824 temperature observations, and 8627 measurable wind chills).**

larger shallow areas of coastal Nova Scotia experienced significant cooling of up to 3°C over the course of the CAO. The locations are: St. Margaret's Bay and Mahone Bay on the South Shore; the south-western tip of Nova Scotia (Cape Sable and off Pubnico); St. Mary's Bay, and Chignecto and Cobequid Bays in the innermost reaches of the Bay of Fundy (see labels, top panel, Fig 7). Except for the South Shore locations, these sites are part of, or near to, the Gulf of Maine and Bay of Fundy which feature large tidal currents and consequently substantial mixing.

We choose mainly to focus our study on the aforementioned coastal locations of Nova Scotia. However, several other coastal areas within the CIOPS-E domain also experienced significant cooling indicating the broad spatial scale response to the CAO (bottom panel, Fig 6): a small area outside Passamaquoddy Bay, New Brunswick; the area off Bar Harbor, Maine, USA; and areas around Cape Cod, Massachusetts, USA. Other areas of large temperature changes on the Scotian Shelf and off the continental shelf are associated with eddies and current meanders; these may or may not have been influenced by the CAO. Analysis of such is beyond the scope of this study.

The southern coast along Anticosti Island in the Gulf of St. Lawrence experienced a substantial *increase* (by ~3°C) in SST during the CAO. This warming is consistent with the upwelling of warmer subsurface water, which would have to come from ~125 m depth based on long-term temperature and salinity climatology (Petrie *et al.* 1996). Based on the Ekman flux, we estimate that the WNW winds that were blowing parallel to the coast of Anticosti Island for most of the CAO (Fig 3) could have made a significant contribution to the upwelling of as much as ~40 m.

Less obvious cooling also appears in narrow near-shore bands along the Atlantic coast of Nova Scotia. The complicated coastlines of this area are not well resolved by the model which may lead to differences with observations.

Modelled SST and sea-bottom temperatures (SBT) at the nearshore study locations (Fig 7) that experienced rapid cooling were not substantially different (not shown). This, combined with the bathymetry of the area (Fig 1), indicates which regions are most susceptible to rapid cooling, namely shallow areas that are easily vertically mixed because of weak stratification and/or strong tidal flows, and do not have ready access to warmer/deeper waters to replenish the local

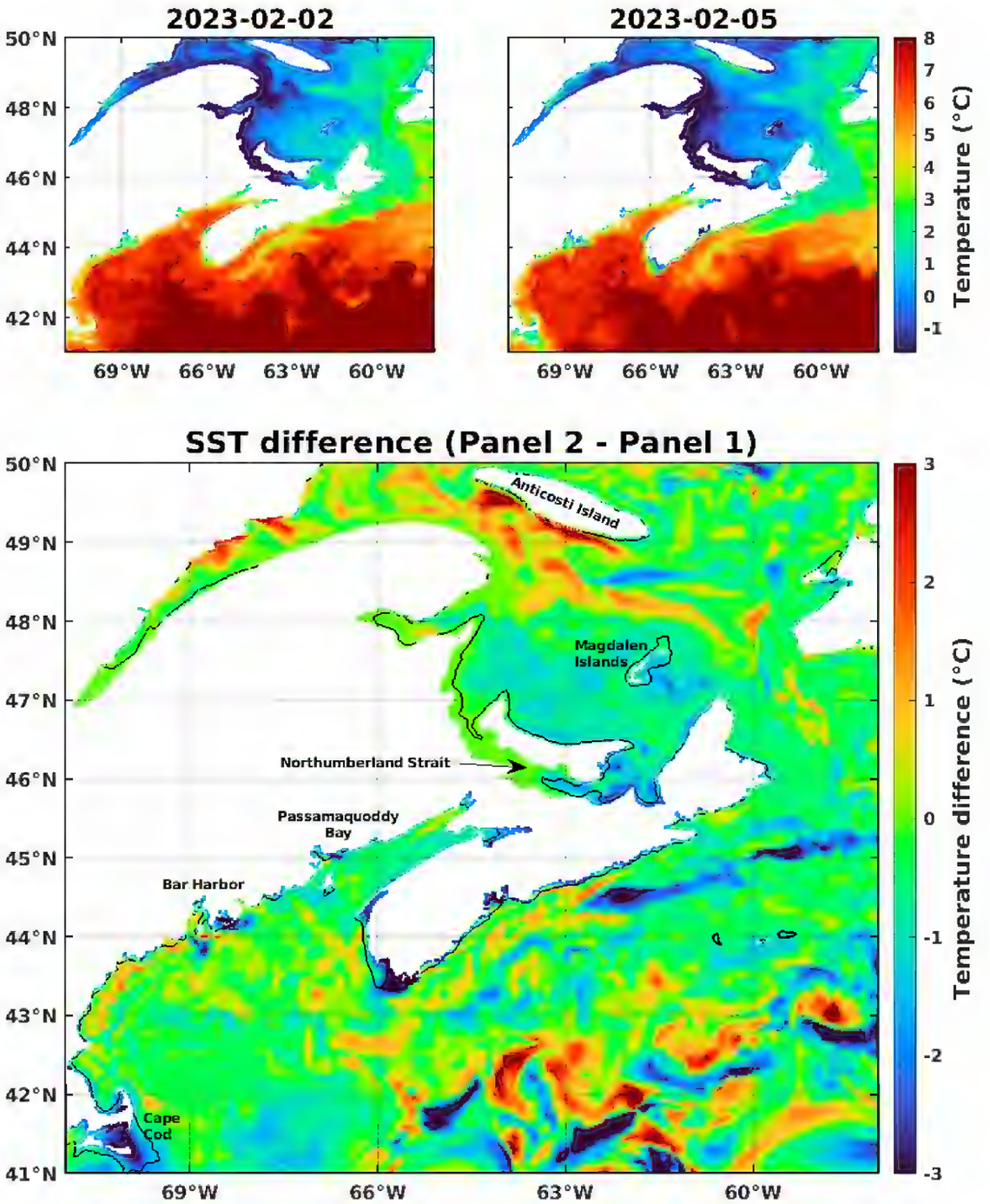

Fig 6 **Model daily-average sea-surface temperatures (°C) for (top left) Feb. 2, and (top right) Feb. 5, 2023, and (bottom) the difference (Feb. 5-Feb. 2) between the two maps. The thin, black line in the lower panel is the 20 m bathymetric contour.**

surface heat loss. During this outbreak, areas that experienced cooling are generally those with very shallow depths (< 20 m, see 20 m bathymetric contour, bottom panel, Fig 6), with temperatures several degrees above freezing before the event onset. In deeper areas, he warmer waters present at depth can be a source of heat that reduces the near-surface temperature drops through vertical mixing or advection.

Temporal evolution of SST in select bays and nearshore areas

To better quantify the response to the CAO in the affected bays, hourly SST time series (middle panel, Fig 7) were extracted from the model at the indicated locations (upper panel, Fig 7). Sudden drops of SSTs during the CAO (shaded in light grey in the middle panel) are important at all locations, on the order of 3°C, with little to no comparative cooling for several days leading up to the CAO. To varying degrees, all locations exhibit temperature fluctuations caused by the semi-diurnal tides moving horizontal temperature gradients at each site. To quantify the temperature drops, the tides were filtered out using a fourth-order low-pass 24-hr Butterworth filter (lower left panel, Fig 7). From the combined filtered and unfiltered results, two temperature behaviours are of note.

Mahone Bay (dark blue) and St. Margaret's Bay (orange) experienced rapid cooling, with temperatures dropping from approximately +1.3 to -1.7°C in both bays, reaching freezing temperatures for salt water midway through the CAO. Temperature variations from the tidal cycle, which were small at the beginning, are much reduced or gone, indicating that horizontal SST gradients have largely been eliminated in these somewhat isolated, shallow areas.

The other locations, which are in areas of strong tidal flows, exhibit temperature fluctuations of varying amplitude associated with the tidal cycle which persist during and after the CAO; this indicates that horizontal temperature gradients have not been eliminated by the surface cooling. Cape Sable (light blue) shows the largest temperature drop, ~6.5°C, from +5.8 to -0.6°C. The smallest drop of 2°C occurred in Chignecto Bay (black), from +1.5 to -0.5°C. The lower right panel of Fig 7 summarizes the modelled responses for each site.

Water temperature variations along St. Mary's Bay

Location within an individual bay can be important. For example, SST in the inner and outer areas of St. Mary's Bay (iSMB and oSMB, purple and yellow curves in Fig 7) show significant differences. The oSMB site is warmer by ~2°C, and in an area where there are substantial horizontal temperature gradients and large tidal excursions (Petrie *et al.* 1996, DFO 2022) hence the temperature varies by up to 6°C with the tides. At iSMB, both the horizontal SST gradient and the tidal excursions are smaller, hence the tidal variation of temperature is also much smaller, 0.25°C. At both iSMB and oSMB

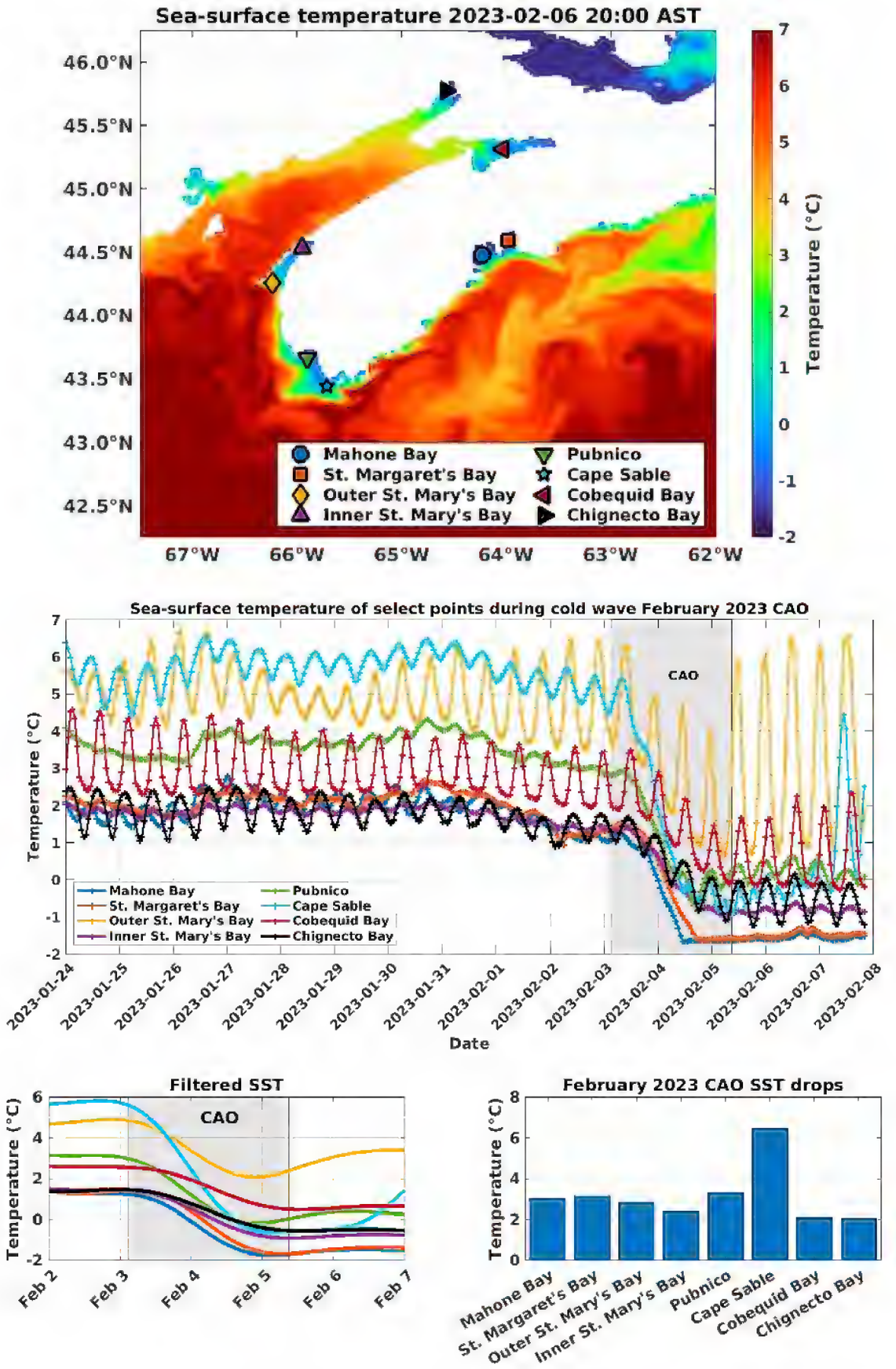

Fig 7 **Top: Model SST (°C) on Feb. 6, 2023, 20:00 AST (after the CAO), and the selected locations for evaluation. Middle: hourly SST time series of model results at those locations before, during, and after the CAO (shaded grey); the colours of the curves match the colour of the symbols in the map. Bottom left: SST, filtered to remove the tidal signal centred on the CAO. Bottom right: calculated SST drops during the CAO from the filtered data.**

the cooling associated with the CAO is overlaid on the tidal signal, with temperatures drops of 2.5 and 3.0°C, respectively.

To illustrate the differences along the length of St. Mary's Bay, a transect along the middle of the bay has been sampled from the model (see map, blue-dashed line, top panel of Fig 8). Hovmöller diagrams of this transect are shown in the lower three panels of the same figure (time on the x-axis, latitude on the y-axis), indicating the evolution of SST, SBT, and the difference between the two (SBT-SST). The evolution of the temperature is clear: before the CAO there is a substantial temperature gradient along the transect that moves with the tides, the waters then cool during the CAO. The difference (SBT-SST) in temperature is ~0°C throughout the period shown, indicating that the transect is vertically well mixed. The only substantial differences between SBT and SST are at the southern-most parts of the transect, south of ~44.15°N, in deeper waters beyond the entrance of SMB, and only appear near the end of the CAO. After the CAO, SST and SBT in the outer areas begin to recover as heat is replenished from the deeper adjacent regions; however, the inner bay remains cold, enhancing the original temperature gradient along SMB.

Comparison of modelled and observed water temperatures during the CAO

Water temperature observations were obtained from eight moorings (locations, Fig 2), all showing significant cooling during the CAO (blue lines, Fig 9). The observed water temperature changes during the CAO, defined by the filtered series and black lines over blue lines, Fig 9, range from 1.0 (Halifax) to 3.9°C (Yarmouth), with an overall average cooling of ~3.0°C (Table 1). This range is comparable to that from the model at its closest location to each observation site (red lines), Fig 9, with filtered series overlaid in black ranging from 1.1 (Port Hawkesbury) to 3.5°C (Shelburne) (Table 1), with an average cooling of 2.3°C. At 5 of the 8 sites, observed temperatures before the onset of the CAO were greater than the modelled values by as much as ~2.5°C (Lunenburg).

The observed and modelled temperature changes at each individual site show evident differences, in particular at Canso where the observed cooling exceeded the model's result by 2.4°C. On the other hand, at Halifax the cooling estimated by the model was 1.5°C greater than observed. Some differences can be attributed to the fact that the model does not properly resolve the coastline features of the

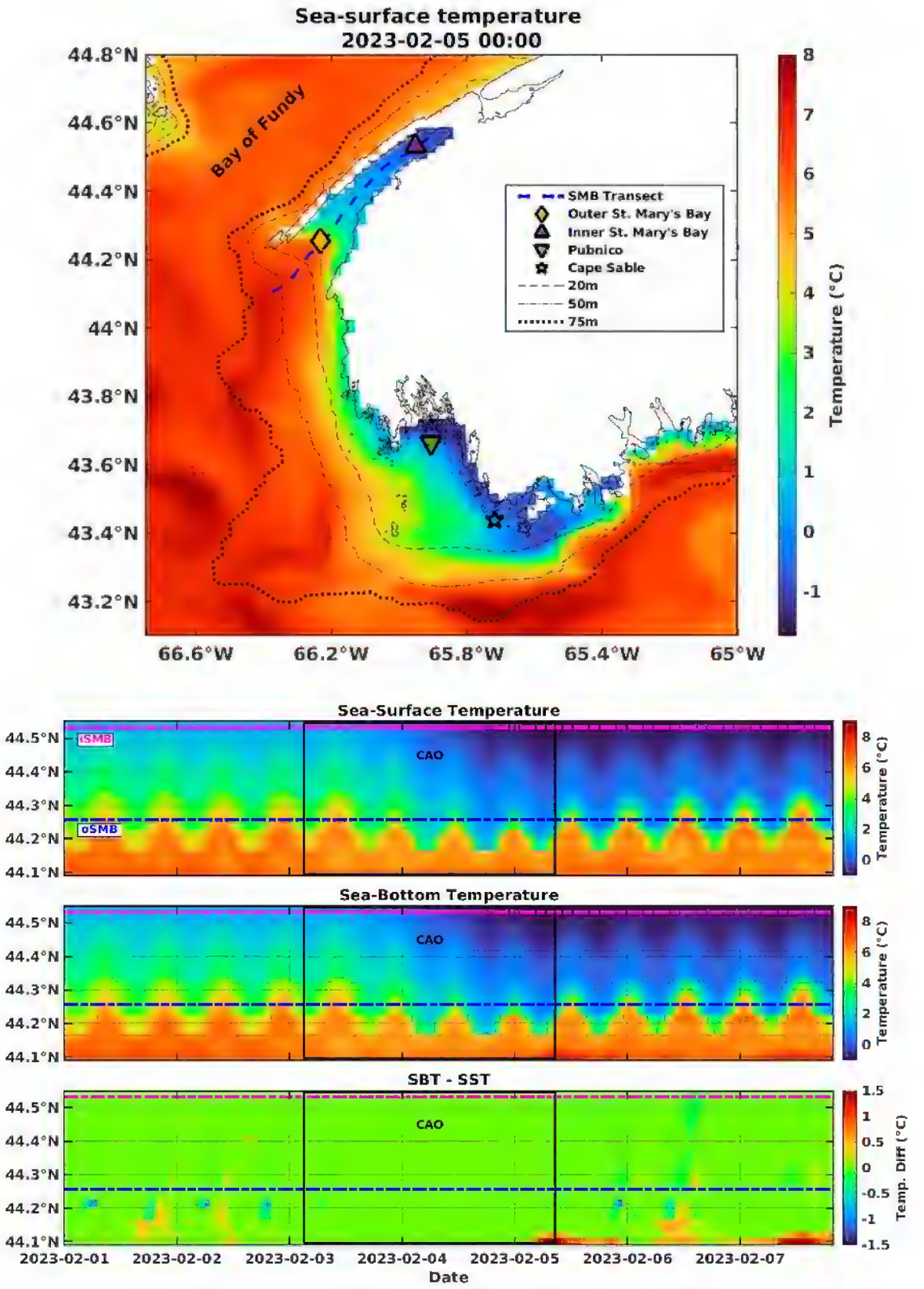

Fig 8 **Top: Model SST (°C) on Feb. 5, 2023, 00:00 (near the end of the CAO) off southwest Nova Scotia, local bathymetry (black dashed lines at indicated depths), and St. Mary's Bay (SMB) transect (blue-dashed line). 2nd, 3rd and 4th panels: Space-time variations of SST, SBT, and the difference between the two (SBT-SST), respectively, along the SMB transect. The locations of iSMB (magenta lines) and oSMB (blue lines) are indicated in each of the bottom three panels. In the lower panels, the latitudes indicate the location along the SMB transect, and hence how these quantities vary over time at each position. The vertical black lines mark the beginning and end of the CAO.**

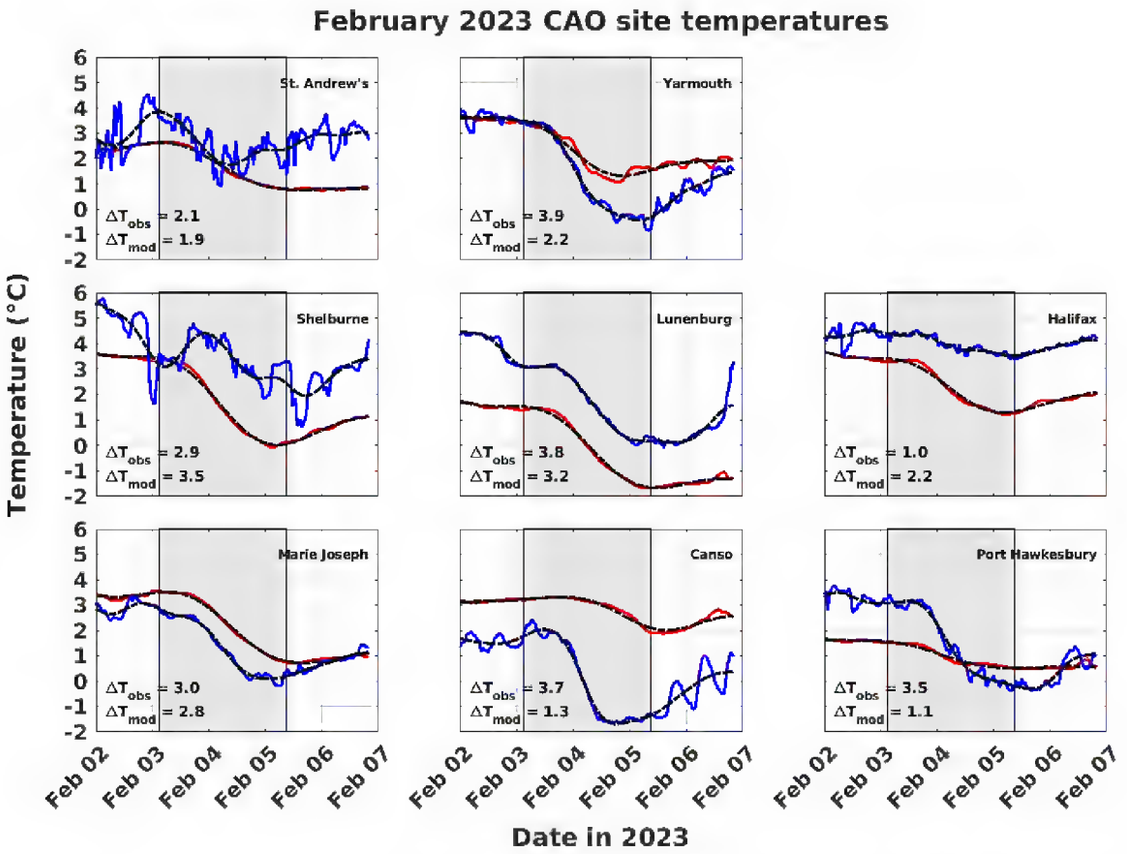

Fig 9 **Water temperatures (°C) from the model (red) and moorings (blue) during the February 2023 CAO (shaded areas) at the indicated locations in Fig 2, along with filtered responses (black lines) used to determine the temperatures changes at each location.**

nearshore mooring sites, e.g. Halifax inlet is not captured. Moreover, the largest difference between modelled and observed cooling is at Canso where the mooring site is in a shallow and sheltered harbour, whereas the closest model grid point has a much larger depth of 82 m. The smaller temperature change in the model may be attributed the greater depth to spread the heat loss to the atmosphere, and the potential for a compensating heat flux from deeper depths through vertical mixing and/or advection.

Sea ice in the Northumberland Strait and other areas

The Northumberland Strait between Prince Edward Island and Nova Scotia/New Brunswick is a shallow area susceptible to rapid cooling during a CAO. However, the SST differences from Fig 6 (lower panel) show no rapid cooling there during the February 2023 CAO. Prior to the CAO on Feb. 2 (left panel), the minimum SST (~ -1.7°C) had already been reached, hence further heat loss will cause ice formation and thickening. Maps of the ice thickness (> 0.01 m) from CIOPS-E show this to be the case (Fig 10). Before the CAO, ice covers the western half of the Northumberland Strait (upper left

panel). Afterwards, ice thickened in many areas, and formed in the eastern areas of the Strait that were previously ice free (upper left and bottom panels). Ice formation is evident in the western Gulf of St. Lawrence and around the Magdalen Islands. Some ice thickening and formation may be due to the wind and water currents moving the ice around, which could compact ice along the coast, or open leads for new ice to form.

During the CAO, the CIOPS-E ice cover in the Northumberland Strait compares favourably to the sea ice concentration estimates available from the Canadian Centre for Meteorological and Environ-

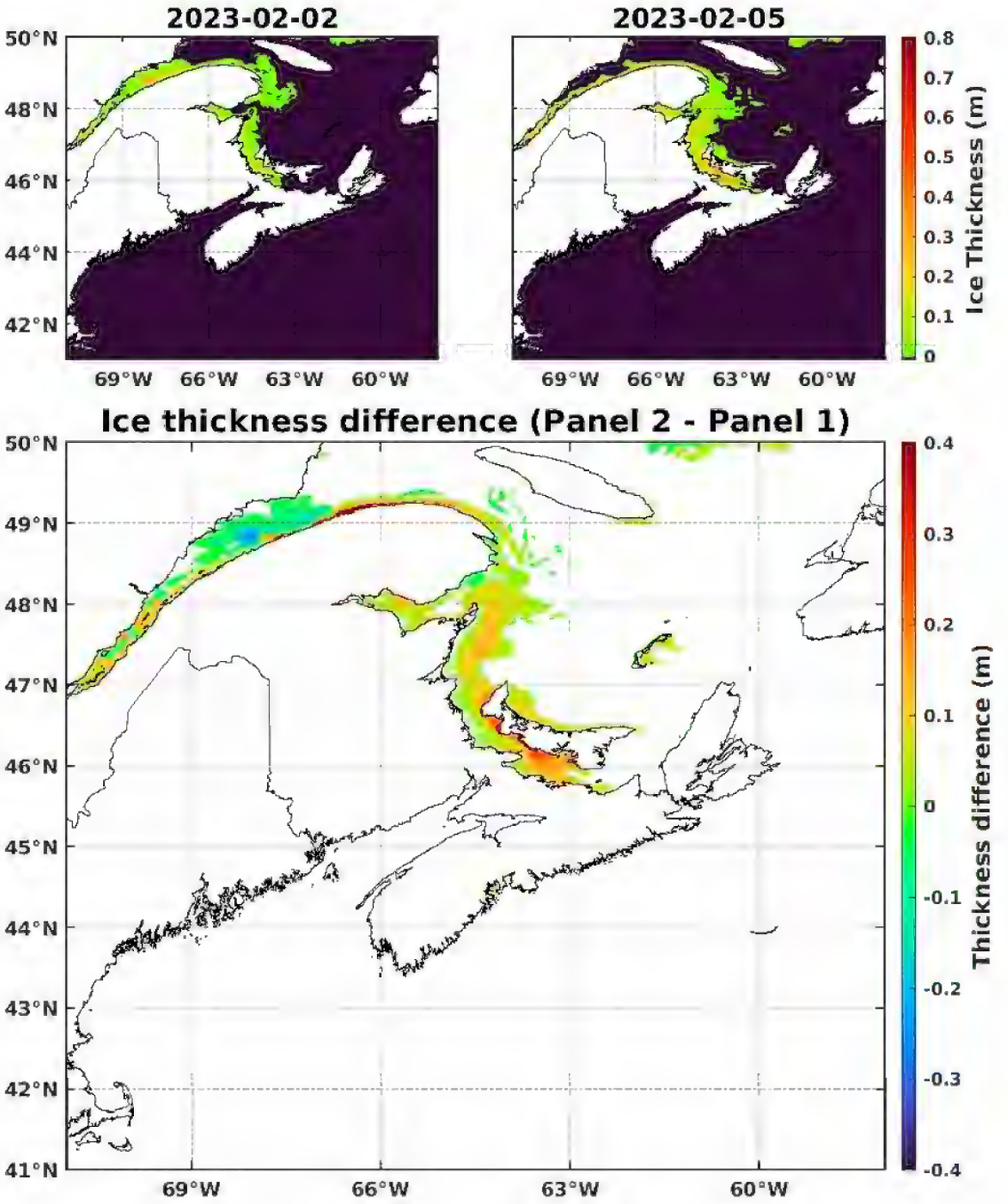

Fig 10 Model ice thickness (m, top left) before and (top right) after the CAO, and (bottom) the difference between the two.

mental Prediction (CCMEP) SST analysis (Fig 11, see Brasnett 2008; Brasnett and Surcel-Colan 2016, for descriptions of the data products). Both CIOPS-E and the CCMEP ice concentration estimates show the ice cover progressing eastward along the Northumberland Strait during the CAO, with CCMEP indicating more ice along the northern shore of Prince Edward Island. Of further note, CIOPS-E suggests ice formation in Mahone and St. Margaret's Bays during the CAO (Fig 10). The SST time series predicted by the model for these locations (Fig 7) suggest how ice formation would progress: prior to the CAO, SST was between 1.0 and 1.5°C, which then rapidly dropped to freezing temperatures (~ -1.6°C) at around midday on Feb. 4, at which point ice formation would begin. However, there were no reports of ice in either bay. Moreover, during the CAO, observed near-surface water temperatures at Lunenburg (on the western edge of Mahone Bay) were about 1.5°C warmer than the model estimates (Fig 9), and remain well above ice formation temperature. This suggests that ice formation in the two bays was unlikely during the CAO. The difference between the model prediction and the observations appears related to the initial conditions (model temperature was ~2.5°C colder) before the onset of the CAO. The cooling predicted by the model and that observed were similar (3.2°C versus 3.8°C). In contrast, observations at Canso approached freezing temperatures, suggesting that ice might begin to form if the CAO had persisted; on the other hand, model predictions were ~3.5°C warmer (Fig 9).

DECEMBER 2016 COLD AIR OUTBREAK

From December 15 to 18, 2016, Atlantic Canada experienced a CAO that was very similar to the one in February 2023 (compare Fig 3 and 12). Fig 13 shows air temperatures and wind chills (upper panel), and wind speeds (middle panel) at the same weather stations as for the February 2023 event. Wind speeds (solid lines) and 'to' directions (red flags, both bottom panel) are shown for a representative subset of those stations at times focused on the CAO. The CAO began part way through Dec. 15, and ended in the early hours of Dec. 17 (shaded areas), lasting slightly less than two days. The coldest average temperatures (~-17°C) during the CAO were recorded in southern New Brunswick, the warmest (~-9°C) in SWNS. Lagged correlations indicate no significant difference in the timing of the

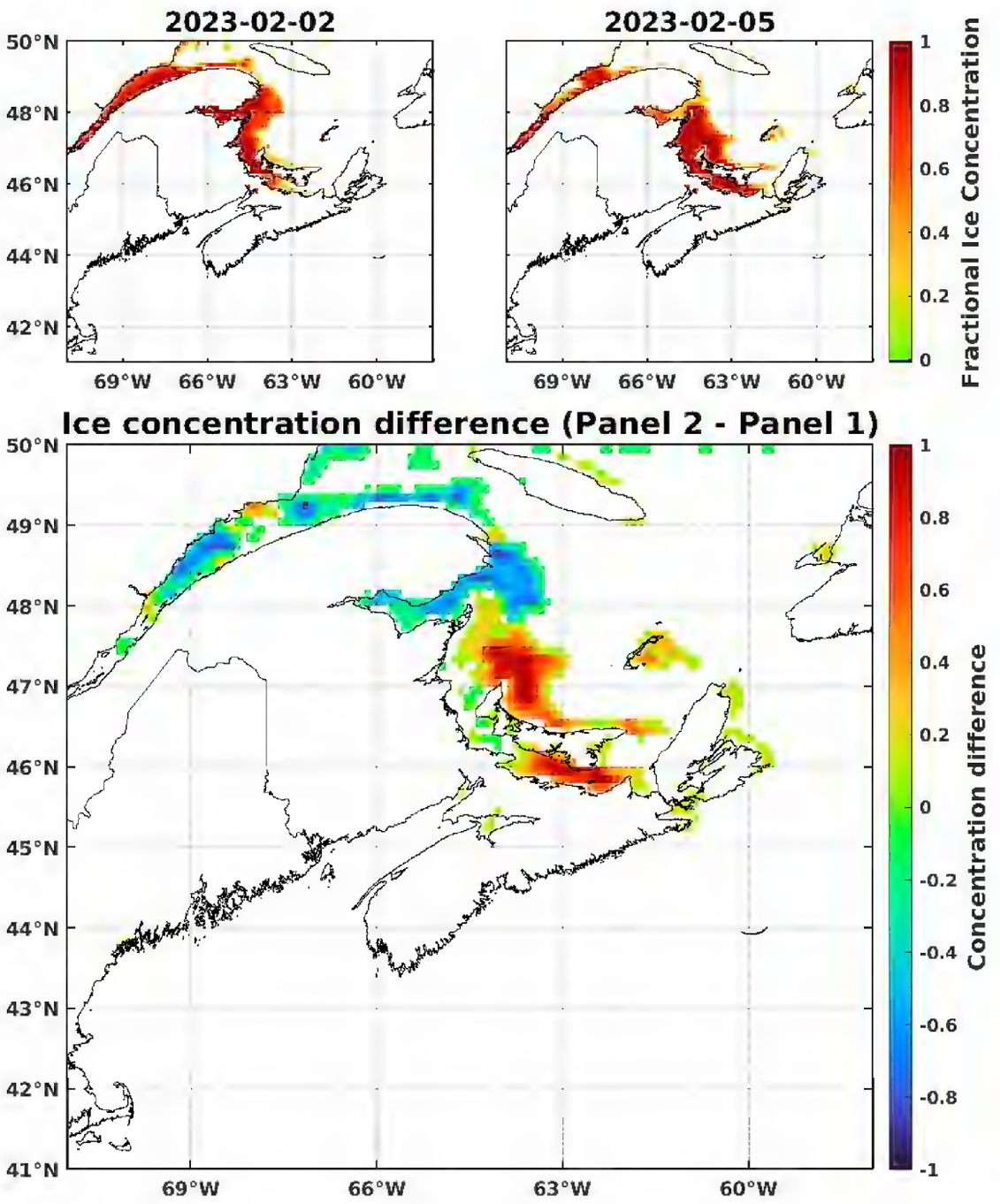

Fig 11 **Satellite estimates of ice concentration before and after the February CAO (upper panels; color shading for fractional ice coverage > 0.15). Lower panel: Difference (Feb. 5-Feb. 2) between ice coverage > |0.10|.**

event across the region. The average correlation between the air temperature series was 0.81 with a standard deviation of 0.14, less coherent than in 2023. Strong, predominantly WNW winds, like the February 2023 CAO, prevailed over the region. The strongest winds were seen at Brier Island and Baccaro Point, with peak speeds of ~80 km/h at the former. The variation of wind chill during the CAO was very similar to the air temperature series: correlations among sites were high, with an average of 0.86 ± 0.10. The region experienced

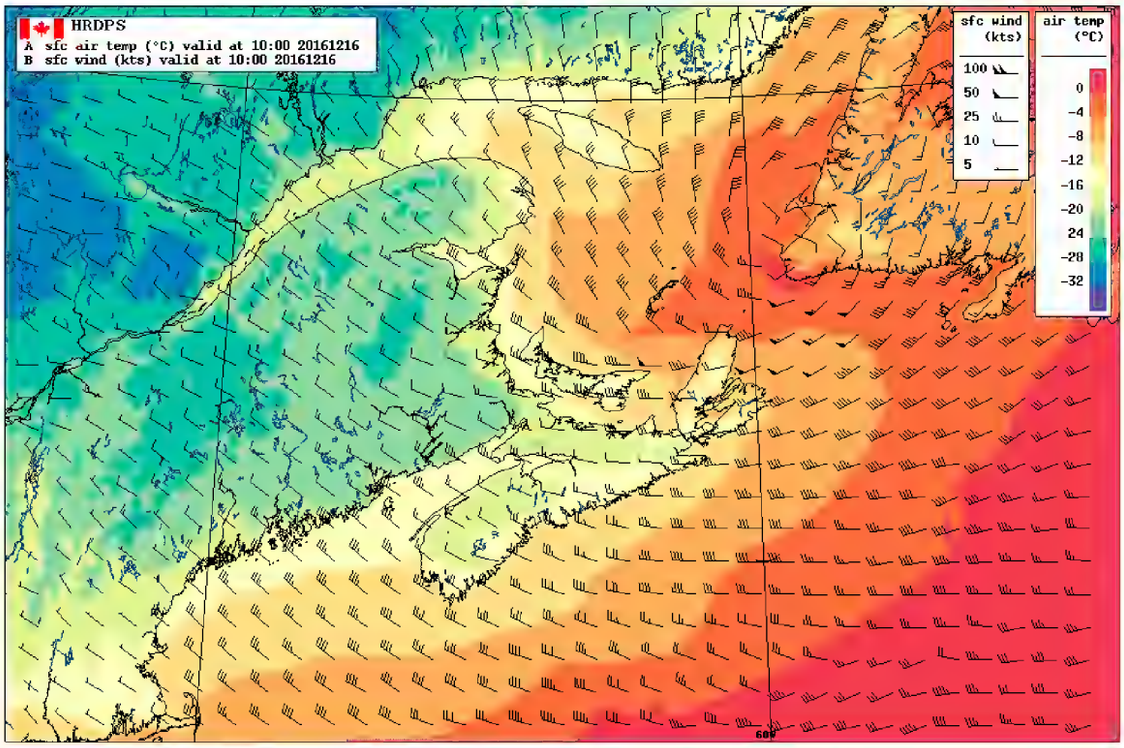

Fig 12 HRDPS-predicted 1.5 m air temperatures and 10 m winds on Dec. 16, 2016, 06:00 AST (10:00 UTC).

wind chills as low as -37°C. Air temperatures and wind chills were extreme compared to hourly December weather conditions for Shearwater from 1993-2022 (Fig 14). Air temperatures were in the lowest 1% of values (< -13°C) for approximately 30 hours beginning on Dec. 16, 02:00. Wind chills were in the lower 1% and 5% of values for 12 and 31 hours, respectively. Significant heat fluxes from the ocean to the atmosphere would have occurred.

Large-scale response of the model

Compared with the February 2023 CAO, the December 2016 CAO occurred ~50 days earlier in the fall/winter season when higher, but gradually decreasing, SSTs would be expected. This is confirmed by CIOPS-E time-series of SSTs (upper panel, Fig 15, same locations as in Fig 7) that show gradual cooling in the weeks prior to and rapid cooling during the CAO (shaded area). Daily average SST maps before (Dec. 15) and after (Dec. 17) the CAO, as well as the difference between the two dates, show cooling patterns similar to the February 2023 CAO in the various bays of interest (Fig 16). There was cooling in the Northumberland Strait, as ice was not present in the region (not shown), with warm enough initial SSTs for the CAO to have an affect here as well. As in 2023, Cape Sable had the largest temperature drop (bottom panels, Fig 15), 6.3°C, from approximately 7.6 to 1.3°C;

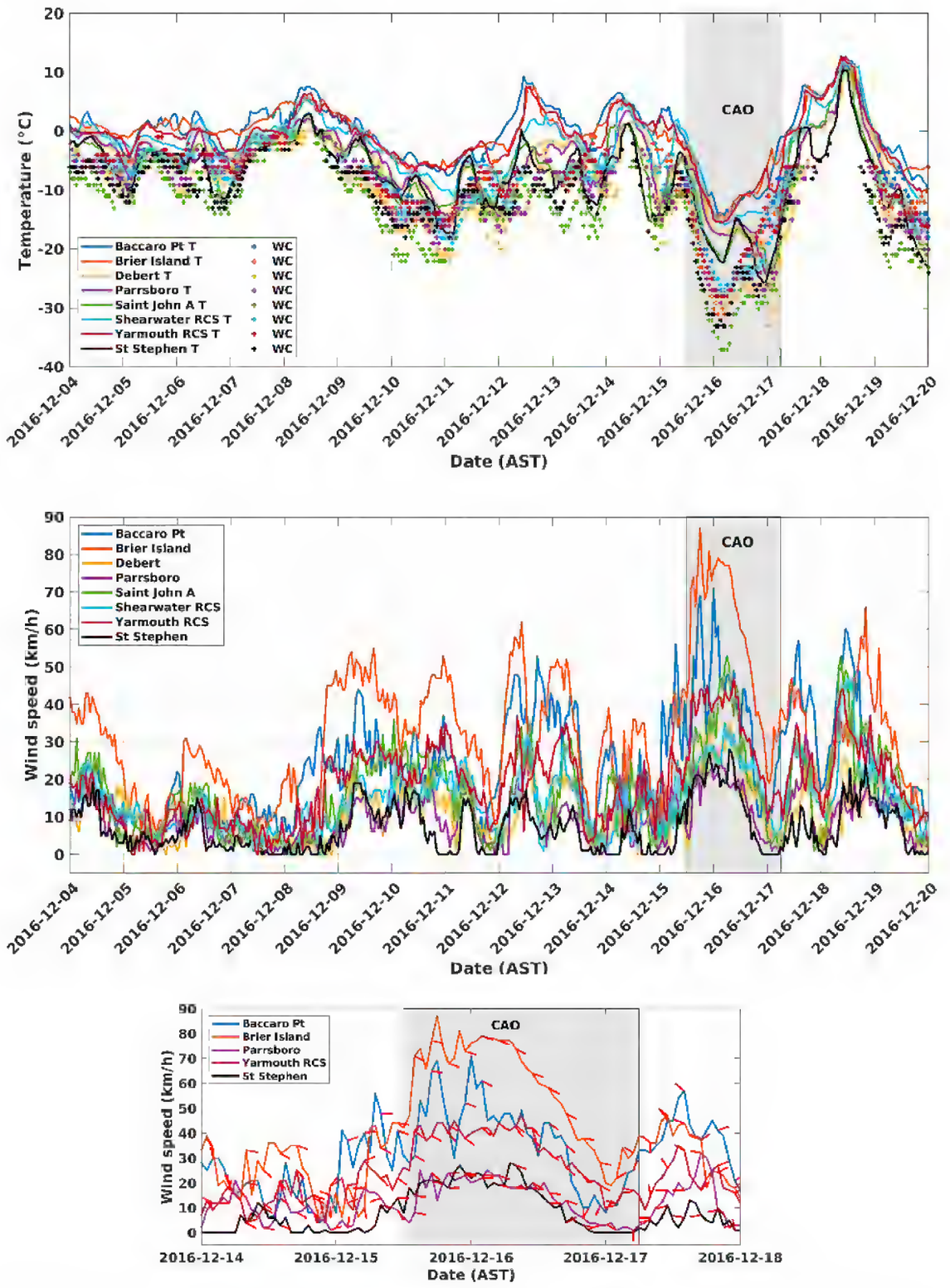

Fig 13 **Top panel: air temperatures (T; solid lines,°C) and wind chills (WC; '+' signs,°C) as measured by the ECCC stations in Fig 1. Middle panel: wind speeds (km/h) at the same sites. Lower panel: wind speed (solid lines) and 'to' directions (short red lines).**

it then rebounded a couple of days later from the intrusion of warmer water. The minimum temperature drop was in Cobequid Bay, 1.7°C, from 5.8 to 4.1°C. All other locations experienced decreases of 1.8 to 2.9°C, including sites in SMB of 2.1°C.

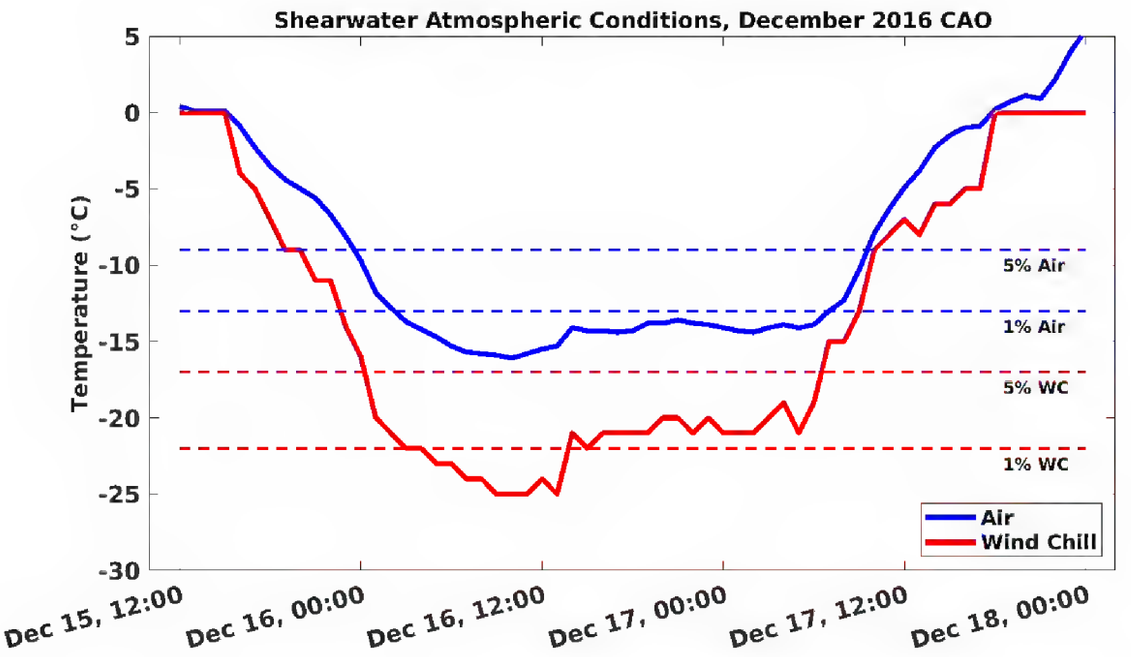

Fig 14 **Time series of air (blue solid) and wind chill (red solid) temperatures (°C) at Shearwater during the December 2016 CAO. The red and blue-dashed horizontal lines indicate the lower 1 and 5 percentile bins for all December hourly observations from 1993 to 2022 (21810 temperature observations, and 9043 measurable wind chills).**

Observations at select sites

Temperature observations (T_{obs}) were available from 15 coastal sites (Fig 2) to compare with the model (T_{mod}). Filtered T_{obs} (Fig 17, Table 1) indicate temperature decreases of 1.0°C (mouth of Mahone Bay) to 3.7°C (Canso); temperature drops in the model were from 0.4°C (Sandford) to 6.3°C (Cape Sable). The averages of the temperature changes associated with the CAO were 1.9°C for the observations and 2.2°C for the model. However, 10 records had the observed temperatures up to ~4°C greater than model values; at 4 sites, the observed and modelled temperatures were essentially equal. As for the 2023 CAO, at Canso the observed temperatures were substantially lower (by 2-5°C) than the model predictions.

From outer St Mary's Bay (Grand Passage, Saulnierville, Meteghan) to the mouth of Mahone Bay, the general tendency is for $\Delta T_{obs} < \Delta T_{mod}$, with an average value of 1.2°C, where Δ indicates a temperature change. Within this group the largest difference, 4.5°C, is for Cape Sable. From Halifax through Sydney the opposite is observed, $\Delta T_{obs} > \Delta T_{mod}$, on average by 0.9°C. The largest difference is for Canso.

Animations of model SST of the area (not shown), and consideration of the wind direction (WNW) give clues to the model response for both CAOs at Cape Sable. Prior to each CAO, Cape Sable is

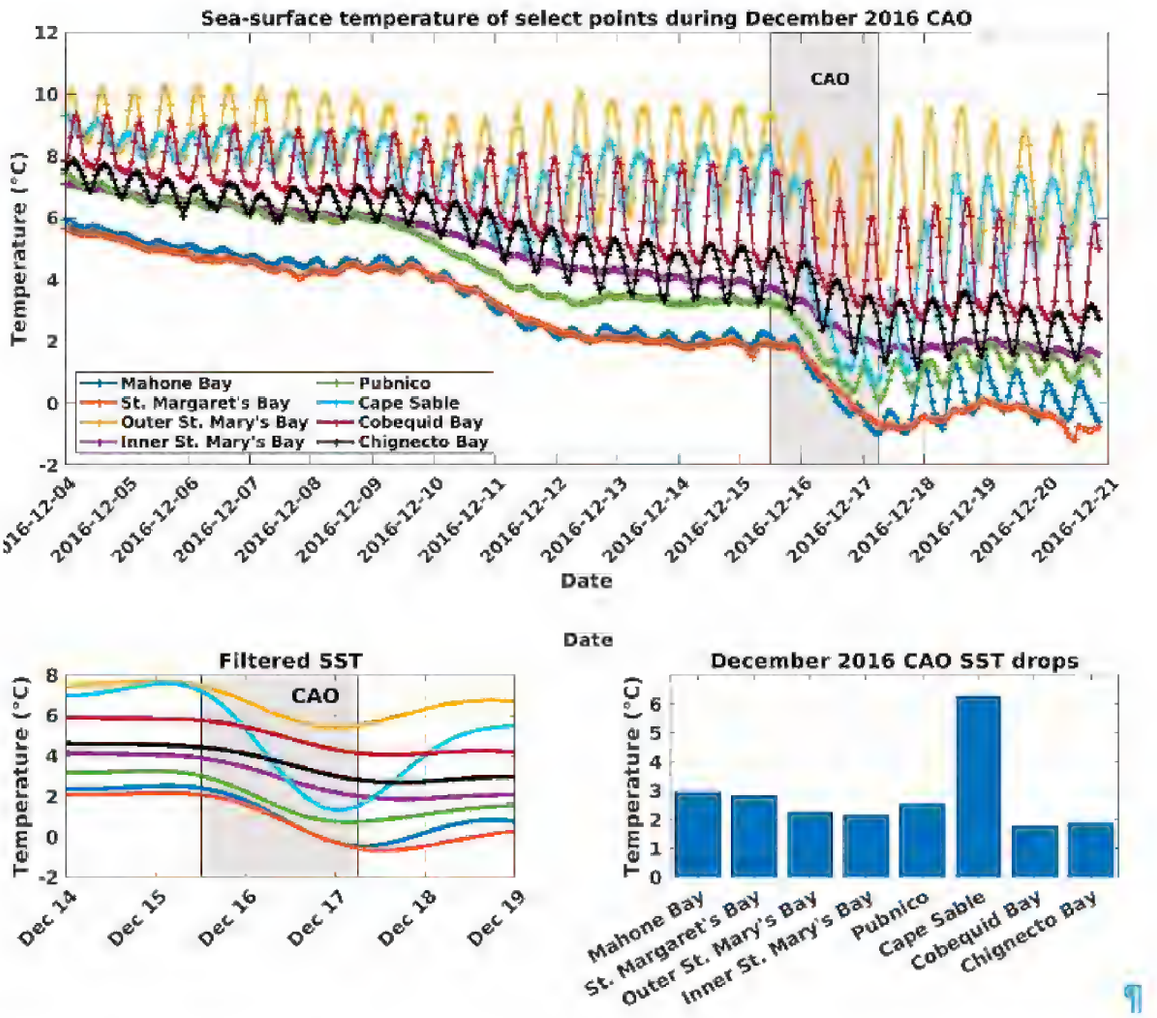

Fig 15 **Top: hourly SST time series (°C) of model results at selected locations (see Fig 7, upper panel) before, during, and after the CAO for the December 2016 CAO. Bottom left: SST filtered to remove tidal signals centred on the CAO. Bottom right: calculated SST drops during the CAO from the filtered data.**

considerably warmer than Pubnico. The CAO wind then drives the colder water in the Pubnico region in the direction of Cape Sable. So, part of the cooling at Cape Sable is from advection of colder water into the area that dominates local cooling. After the CAO, wind patterns change, and warmer waters flow back to Cape Sable, restoring the initial conditions that prevailed in December 2016. Compared to observations, the model appears to be overestimating the temperature gradient between Pubnico and Cape Sable.

Observations in iSMB (where the latter stages of the fish kill occurred) are not available. The model predicts a drop of about 2°C in the area; however, given the lack of *in-situ* data for verification, this is not sufficient to conclude that the CAO contributed to the fish kill.

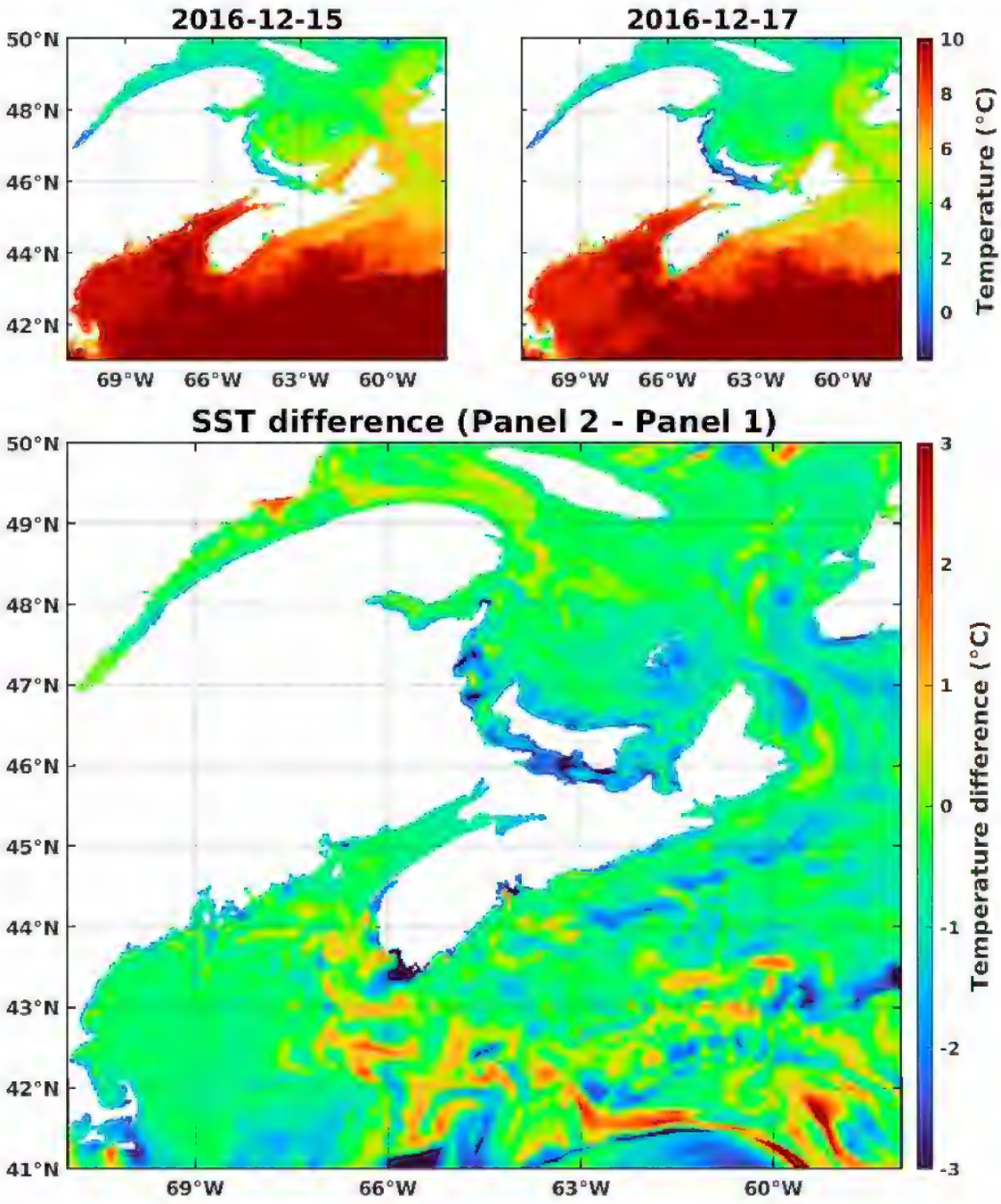

Fig 16 **Model daily-average sea-surface temperatures (°C) for (top left) Dec. 15 and (top right) Dec. 17, 2016, and (bottom) the difference (Dec. 17-Dec. 15) between the two maps.**

CONCLUSIONS

The recently developed CIOPS-E system provides short-term (48h) operational forecasts and continuous "pseudo-analysis" of past (2016-present) ocean conditions in Atlantic Canada. Here, we analyzed the space-time variations of ocean temperature from the pseudo-analysis during two short-lived (2.5 days or less), extreme cold air outbreaks in December 2016 and February 2023 for coastal areas from Cape Breton to the Bay of Fundy. For both events, model

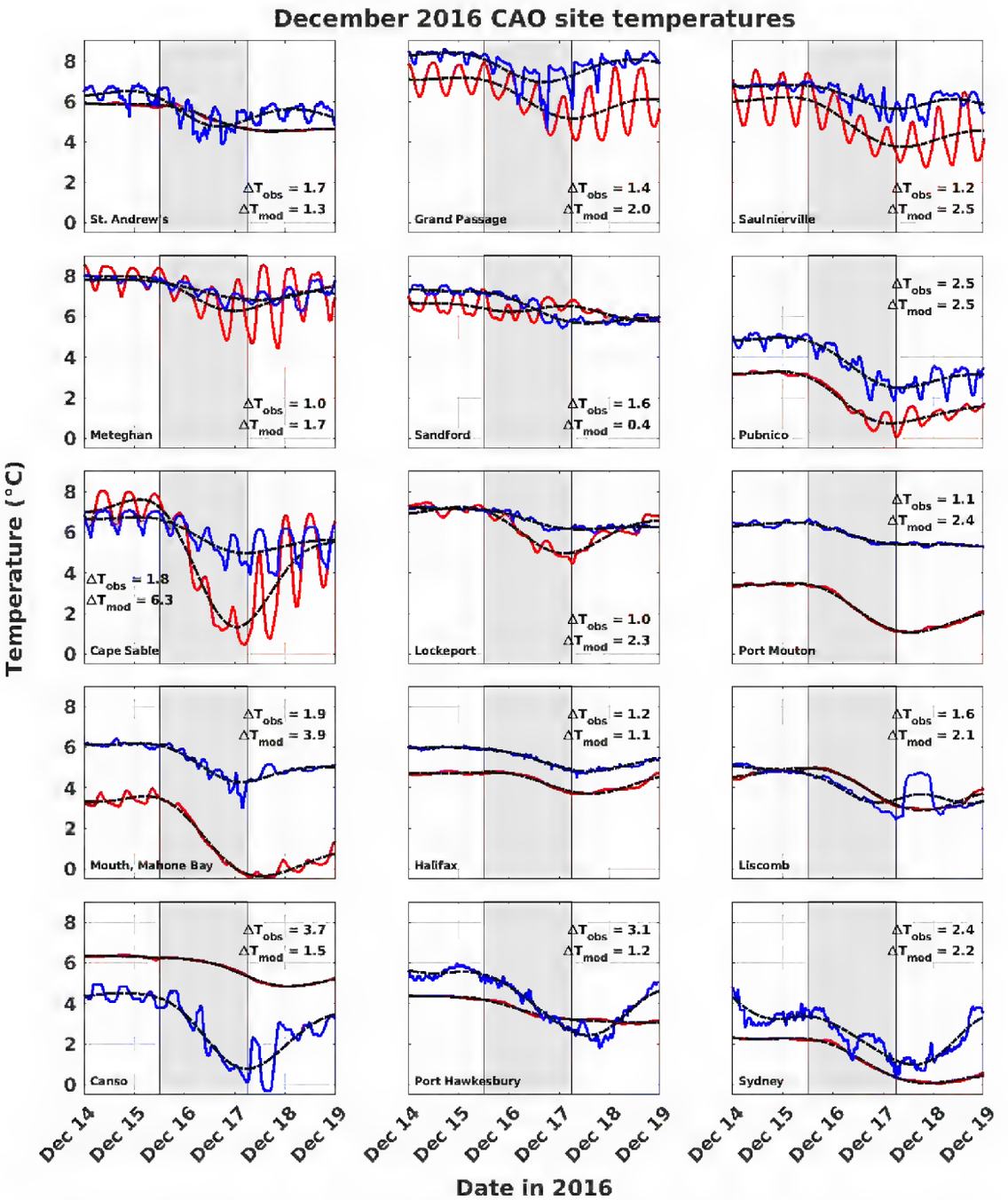
December 2016 CAO site temperatures
Temperature (°C)
St. Andrews ΔTobs = 1.7 ΔTmod = 1.3
Grand Passage ΔTobs = 1.4 ΔTmod = 2.0
Saulnierville ΔTobs = 1.2 ΔTmod = 2.5
Meteghan ΔTobs = 1.0 ΔTmod = 1.7
Sandford ΔTobs = 1.6 ΔTmod = 0.4
Pubnico ΔTobs = 2.5 ΔTmod = 2.5
Cape Sable ΔTobs = 1.8 ΔTmod = 6.3
Lockeport ΔTobs = 1.0 ΔTmod = 2.3
Port Mouton ΔTobs = 1.1 ΔTmod = 2.4
Mouth, Mahone Bay ΔTobs = 1.9 ΔTmod = 3.9
Halifax ΔTobs = 1.2 ΔTmod = 1.1
Liscomb ΔTobs = 1.6 ΔTmod = 2.1
Canso ΔTobs = 3.7 ΔTmod = 1.5
Port Hawkesbury ΔTobs = 3.1 ΔTmod = 1.2
Sydney ΔTobs = 2.4 ΔTmod = 2.2
Dec 14 Dec 15 Dec 16 Dec 17 Dec 18 Dec 19
Date in 2016

Fig 17 Water temperatures (°C) from the model (red) and moorings (blue) during the December 2016 CAO (shaded areas) at the indicated locations, along with filtered responses (black lines) used to determine the temperatures changes at each location.

results show SST drops of 1.5 to 5°C in relatively isolated shallow bays and straits. Regional averages of the temperature changes at common observation and model sites agreed to within 0.3°C (2016) and 0.7°C (2023), though differences between individual sites were large, -1.2°C to 2.4°C in 2016, and -4.5°C to 2.2°C in 2023. Overall, this suggests that the model is capturing the heat flux from the coastal ocean to the atmosphere during a CAO event. At the scale of individual bays, this is not the case. The mismatch of initial conditions

in the model as compared to the observations, and inadequate resolution of coastal topography, have been identified as two potential sources of these discrepancies. In addition, there are systematic differences between model estimates and observed temperatures, namely, for the 2016 CAO, model values were greater than observations for the western half of the region, less for the eastern half; for the 2023 event, model temperatures were greater for the eastern half. These results suggest that broader scale intercomparisons of temperature fields over the adjacent shelf are warranted. One could then determine if mixing with, and advection of, deeper, offshore waters are captured properly by the model.

Around Nova Scotia, the model identifies bays and regions that are particularly susceptible to rapid cooling: St. Margaret's, Mahone, St. Mary's, Cobequid, and Chignecto Bays, as well as the Pubnico/Cape Sable shallow areas immediately off the coast of southwest Nova Scotia. Shallow areas with reduced access to deeper waters, either through mixing or advection, should be more vulnerable to rapid, substantial cooling. The Northumberland Strait between Nova Scotia and Prince Edward Island can also experience rapid cooling and ice formation. The ice modelling reported for the 2023 CAO event successfully reproduced the observed ice formation and growth in the Strait and western Gulf of St. Lawrence, providing support for the validity of the model.

Fish kills have been attributed to CAOs in Florida and Japan. An extensive mackerel die-off in Newfoundland occurred during a sustained period of cold temperatures and low wind chills. The December 2016 CAO featured a sudden drop in water temperatures that might have contributed to the latter stages of the concurrent fish kill in St. Mary's Bay, although a definitive explanation has not been reached. Nonetheless, this study has shown that operational ocean forecasts have the potential to be useful tools that will benefit the siting, assessment, protection and management of marine ecosystems, fishing resources, and the aquaculture industry.

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and Gregory Smith. We particularly appreciate the many inspiring discussions with the late Professor Keith Thompson of Dalhousie University regarding the December 2016 CAO event. We thank the reviewers for their insightful and constructive comments, and the journal Editors for valuable instructions.

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HOMALOTHECIELLA SUBCAPILLATA (HEDW.) BROTH., A NEW MOSS SPECIES TO CANADA FROM OLD BROADLEAVED FORESTS OF NOVA SCOTIA

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ABSTRACT

We report *Homalotheciella subcapillata* (Hedw.) Broth. for the first time in Nova Scotia, found in the western-most part of the province. Upon examination of a previously reported collection of this species from Saskatchewan, we determined that the previous collection was misidentified and conclude that our collections represent the first records of this species for Canada. The moss was found to grow only on old beech (*Fagus grandifolia* Ehrh.) trees in mature to old growth mixed broadleaved forests. The species has likely been present in Nova Scotia for many decades but was not previously detected due to low search effort. Given the apparent rarity and substrate specificity, the decline of its host tree, and the fact that it is threatened or vulnerable in the USA, we recommend that steps be taken to conserve this species and its habitats in Nova Scotia.

Keywords: arboreal, Brachytheciaceae, bryophyte, epiphyte, moss

INTRODUCTION

Homalotheciella subcapillata (Hedw.) Broth. is a rare pleurocarpous moss that is known from forested habitats of eastern North America. It is an eastern North American endemic (Crum & Anderson 1981, Allen 2014), and was formerly known from across much of the American northeast, but appears to have declined from its original extent. It may have become extirpated in New York, Massachusetts, and Vermont, and is considered imperiled in Pennsylvania and

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vulnerable in Tennessee (NatureServe 2022). As recently as 2014, Maine (USA) was thought to be the northern extent of its range (Allen 2014).

Homalotheciella subcapillata typically grows on the bark of the lower bole of hardwood trees in old growth deciduous or mixedwood forests. Crum and Anderson (1981) describe it as being associated with oak-hickory forests, but most other authors have been less specific, merely referring to it as being corticolous or epiphytic, and even suggesting that it can be found on substrates from rotting wood to rock (Allen 2014, Bryophyte Editorial Committee 2014).

Southwest Nova Scotia hosts many unique plant assemblages, due to its combination of temperate climate, maritime humidity, and abundance of wetlands (e.g., Keddy and Wisheu 1989), but certain ecosystems and taxa remain understudied. The bryophyte flora of Nova Scotia is thought to be particularly diverse. Recent reports suggest almost 400 moss species are known (Belland 2010), in addition to at least 127 liverwort and 4 hornwort species (Haughian *et al.* 2016). Although the bryophyte flora of Nova Scotia has been comparatively well-studied from a Canadian perspective (Erskine 1968, Erskine 1970, Ireland 1982, Ireland & Bellolio-Trucco 1987, Bagnell *et al.* 1993, Basquill *et al.* 2024), it remains considerably less well-known than that found in many jurisdictions of North America and Europe that have a longer history of both amateur and professional bryological contributions. There remain many geographic, ecological, and taxonomic gaps in the provincial herbarium collections (Haughian 2022). One such ecological gap is mature to old growth hardwood forests that are dominated by American beech (*Fagus grandifolia* Ehrh.), particularly in the southwest of the province. Consequently, we initiated surveys for rare bryophytes in mature to old growth, beech-dominated forests in southwestern Nova Scotia, with an emphasis on those species reported from mature hardwood forests in the Appalachian and Atlantic Coastal Plain regions of the eastern United States.

METHODS

Study area

Although still part of the Atlantic Maritime Ecozone (Wiken 1986), Digby County, where this work took place, is warmer than much of Atlantic Canada. The weather station in Yarmouth, approximately 25 km south of the study area, reports mean daily temperatures of

-2.6°C in January and 17.3°C in July, and an average of 1290 mm of precipitation per year, most of which falls as rain (Environment and Climate Change Canada 2022). In western parts of Digby County, the land is low-lying (≤ 150 m above sea level) and gently undulating due to the frequent presence of drumlins within a predominantly till-plain; parent materials are typically slate, schist, or graywacke, and soils are typically gravelly or sandy-loam tills, with small-scale variation based mainly on slope position (Neily *et al.* 2017). Ecologically, most of the area is forested, with well-drained positions dominated by climax forests of Eastern Hemlock (*Tsuga canadensis* (L.) Carrière), Red Spruce (*Picea rubens* Sarg.), American Beech, Sugar Maple (*Acer saccharum* Marsh.), and Yellow Birch (*Betula alleghaniensis* Britton), and lowland forests dominated by Black Spruce (*Picea mariana* (Mill.) Britton, Sterns & Poggenburg), Tamarack (*Larix laricina* (Du Roi) K. Koch), and Red Maple (*Acer rubrum* L.). The primary agent of natural disturbance is infrequent hurricane-caused blowdown (Neily *et al.* 2017).

Site selection focused on well-drained stands of old growth mixed deciduous forest that had a beech component, based on the experience of the authors as a result of over two decades of surveying epiphytic lichens and mosses in this region, and as confirmed by driving down approximately 646 kilometers of forest roads while visually assessing canopy composition. Once potential sites were identified (30 in total), surveyors inspected them on foot, following the intelligent meander approach (Mueller-Dombois & Ellenberg 1974). Key habitat features that observers were searching for included the presence of either large or gnarled and stunted beech trees, with abundant coverage by bryophytes on the lower bole, a dense forest canopy (70-90% crown closure), and little to no obvious evidence of recent human disturbance.

Loans of three *Homalotheciela subcapillata* specimens from other herbaria were acquired for comparison purposes. Both field collected and herbarium specimens were examined using light microscopy and regionally appropriate taxonomic keys (Crum & Anderson 1981, Allen 2014, Bryophyte Editorial Committee 2014). Nomenclature follows the most recent published treatments (Bryophyte Editorial Committee 2014).

RESULTS

All three of the loaned herbarium specimens of *Homalotheciella subcapillata* were determined to be species other than the target. The two specimens from the United States were both determined to be *Pylaisia selwynii* Kindb., on the basis of branch tips that were consistently curved away from the substrate; leaf apices that were gradually attenuate, rather than abruptly apiculate; the apparent lack of a visible costa, and the large alar regions bearing upwards of 20 short quadrate cells in 6-10 rows, as compared with only 6-12 cells in 2-5 rows for *H. subcapillata.*

The single Canadian specimen previously identified as *Homalotheciella subcapillata* was from the base of a trembling aspen tree (*Populus tremuloides*) in Saskatchewan, well outside of the range of the species in North America. This specimen was examined, and its identity revised to be *Brachytheciastrum collinum* (Schleicher ex Müller Hal.) Ignatov & Huttunen on the basis of the following:

Colony forming a dense mat to turf (~ 0.5 cm thick) of yellow-green, interwoven shoots, with at least the distal most half of plants erect to ascending; shoots 1-3 cm long, by 0.6-0.9 mm wide (stems to 0.2 mm wide); irregularly branched and often julaceous, with leaves closely imbricate, and shoot tips often falcate; stem leaves ovate-deltoid, approximately 1.0 mm long by 0.5 mm wide, with tips acute to short-acuminate, margins serrulate to serrate throughout, and alar regions with 2-4 rows of small, quadrate or subquadrate alar cells, extending 8-12 cells up the margins; leaf costa single, well-demarcated, and 0.4-0.6 the length of the leaf, with the dorsal surface somewhat prorate; branch leaves similar to stem leaves, but more narrowly deltoid; perichaetial leaves narrowly deltoid at base, acuminate-lanceolate at tip, to 3 mm long by 0.6 mm wide.

The first specimen of *Homalotheciella subcapillata* was discovered in Nova Scotia in a mature hardwood forest of Digby County, Nova Scotia, in April, 2021. This area is part of the Clare Ecodistrict of the Southwest Ecoregion (Neily *et al.* 2017). The forest was dominated by sugar maple (Acer saccharum) and American beech (*Fagus americana*). Other tree species included red maple, yellow birch, and white ash. The species was detected on the lowest 3 m of the bole of a mature American Beech, which was approx. 20 cm diameter at 1.3 m from the ground.

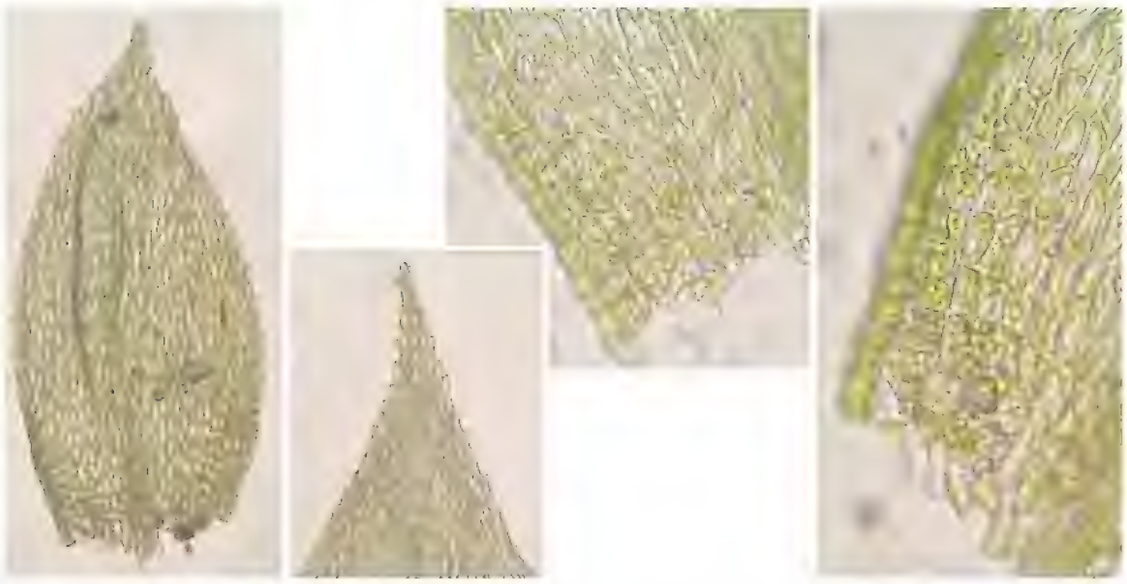

Fig 1 **Leaves of *Brachytheciastrum collinum*, formerly considered to be the first record of *Homalotheciella subcapillata* in Canada, emphasizing overall leaf shape (a), leaf apex (b), and alar regions (c and d).**

The colony had the following properties: Colony forming loose to dense, patchy mats with a yellowish-tinged, medium green colour, with shiny appearance (Fig 2); habit decumbent, with the first 2/3 of a shoot appressed against the bole and tending to grow in a downwards trajectory, and the last 1/3 becoming erect-pendulous, and giving an overall shingle-like appearance to the colony; primary shoots approx. 1.9 mm wide (stems approx. 0.2 mm) and to 2.7 cm long, branching pinnate to subpinnate, branches approximately 1.1 mm wide by 8 mm long; stem cortical cells small and thick-walled; stem and branch leaves erect-spreading, slightly imbricate to crowded but never julaceous, with a mean size of 1.2 mm long by 0.75 mm wide, ovate-elliptical in shape, with a long-apiculate apex (Fig 3); costa ending slightly above the mid-leaf to slightly below the apiculus; leaf margins serrulate; leaf lamina smooth (not plicate); leaf cells to 6 x longer than wide; alar regions with 3-5 rows of small, quadrate alar cells, extending 10-13 cells up the margins; sporophytes and reproductive features absent (colonies sterile).

After our first discovery of *H. subcapillata* in Nova Scotia, twelve more occupied trees were found within 30 km of the original (Fig 4), also on beech and in mature to old growth mixed hardwood forests (Table 1). All forests were well drained and they tended to be dominated by sugar maple, beech, and yellow birch (Table 1). Three of these occurrences were published online via the iNaturalist platform

Fig 2 **Habit of *Homalotheciella subcapillata* in-situ on American Beech trees in Digby County, Nova Scotia.**

Fig 3 **Stem leaves shown under 100 × magnification (a-c), alar region of stem leaf shown at 100 × magnification, and transverse section of mature stem shown at 400 × magnification.**

(Ueda *et al.* 2017), including the first record, whereas others had voucher specimens collected that were donated to the E.C. Smith Herbarium at Acadia University.

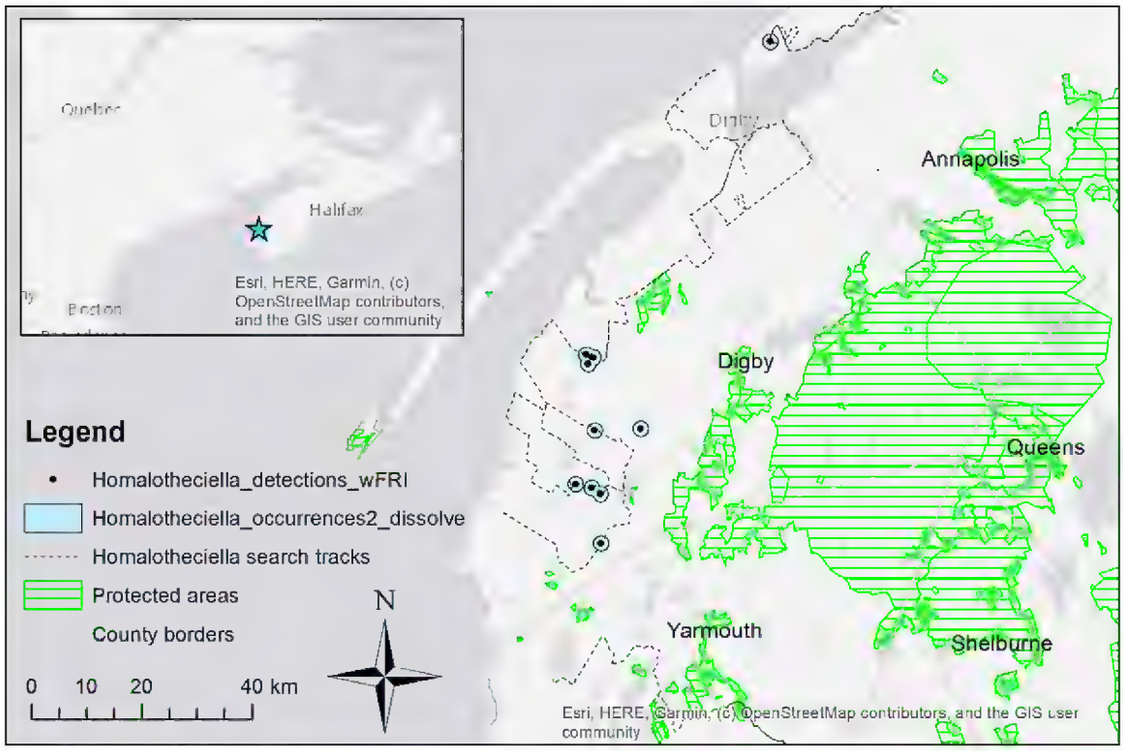

Fig 4 Distribution of detections, occurrences, and search tracks for *Homalotheciella subcapillata* in western Nova Scotia.

DISCUSSION

As is clearly visible from the more elliptical leaf shape and the shorter apiculus, and as is apparent from the differences in growth habit, the previously purported first record for *Homalotheciella subcapillata* in Canada is actually a specimen of *Brachytheciastrum collinum*. Consequently, we regard our specimen, now in the Nova Scotia Museum of Natural History herbarium, as the first record of *H. subcapillata* in Canada.

It is difficult to say whether this occurrence represents a new colonization from places where the species is less rare (e.g., the southeastern United States), or a residual population from pre-industrial times, but we believe that the latter scenario is more likely for several reasons. First, several other bryophyte and lichen species in Nova Scotia have seen apparent population size increases in recent years due to expanded search effort, but had been known to occur in the province for several decades and have actually shown declines in abundance at repeatedly visited sites (e.g., *Pannaria lurida*: Maass 1986, COSEWIC 2016). Consequently, an increased number of occurrences for such taxa in Nova Scotia can contradict apparent population trends, particularly for under-studied ecosystems and taxa. Second, although

Table 1 **Characteristics of forest stands within which *Homalotheciella subcapillata* was detected. Stand structure, canopy composition, and basal area traits were all determined from provincial forest inventory data, which are interpreted from aerial photography (Province of Nova Scotia 2017). Depth to water table was based on the provincial wet areas mapping model (Province of Nova Scotia 2007).**

				Structure		Percent of canopy							Basal area (m^2/ha)			
Site name	Longitude	Latitude	Aerial photo year	Estimated crown closure	Estimated canopy height	*Abies balsamea*	*Acer rubrum*	*Acer saccharum*	*Betula alleghaniensis*	*Betula papyrifera*	*Fagus grandifolia*	*Picea rubens*	*Pinus strobus*	Softwood	Hardwood	Stand size (ha)	Estimated depth to water table (cm)
Hs1	-65.981	44.126	2010	75	12	20	30			40	10			7	16	8.66	532.50
Hs2	-65.982	44.184	2010	65	16		10	50	10		30			0	22	2.69	423.75
Hs3	-65.997	44.343	2011	65	15			40	20		20	20		7	16	12.41	101.00
Hs4	-66.002	44.336	2011	60	16			30	40		20	10		3	18	1.30	253.50
Hs5	-65.997	44.191	2010	65	19			50	20		30			0	25	16.97	1152.00
Hs6	-65.997	44.191	2010	65	19			50	20		30			0	25	16.97	1152.00
Hs7	-65.994	44.343	2011	65	15			40	20		20	20		7	16	12.41	573.25
Hs8	-66.006	44.346	2011	70	14			40	30		20	10		4	19	3.98	568.50
Hs9	-65.992	44.258	2011	90	7		20	40	20		20			0	15	4.46	1032.25
Hs10	-65.917	44.260	2011	70	14	10	40					30	20	21	8	3.74	112.50
Hs11	-66.023	44.195	2010	35	15		20	20			60			0	11	9.33	466.75
Hs12	-66.002	44.336	2011	60	16			30	40		20	10		3	18	1.30	229.00
Hs13	-66.002	44.335	2011	60	16			30	40		20	10		3	18	1.30	260.25
Hs14	-65.706	44.710	2012	80	12	20	30			40	10			4	19	11.78	1067.50

the first record of this species was from a mature forest in a private woodlot, this stand had been minimally managed (selective harvesting for firewood) for several decades, and the majority of stands this species was subsequently found within (Table 1) were old or old growth forests that had likely existed before the widespread use of industrial forest harvesting. Consequently, the species' habitats have likely been intact and minimally managed for at least several decades, and probably for close to a century. Third, the nearest source colony from which propagules could come outside of Nova Scotia is Maine, USA, over 100 km away across the Gulf of Maine, and the species is neither abundant nor common in most of its eastern North American range, so viable propagules are unlikely to reach Nova Scotia in large quantities on a regular basis. Finally, the species occurred in just under half of sites that appeared to have suitable host trees and were inspected on foot, and sites that were considered worth inspecting

were few and far between, suggesting that dispersal or establishment may be somewhat limited.

American Beech is thus far the only tree known to be a substrate for *Homalotheciella subcapillata* in Nova Scotia. This tree has been recently re-classified from "apparently secure" (S4) to "may be at risk / apparently secure" (S3S4), according to Natureserve subnational ranks. This change is primarily due to the rapid expansion of beech leaf-miner beetles (Sweeney & Johns 2016) and subsequent dieback of beech forest throughout the province. Mature, healthy beech forests have already become a rarity as a result of the widespread prevalence of beech canker disease in the province (Houston 1994). Furthermore, as a result of extensive land clearing and forest harvesting, mature to old growth hardwood forests in Nova Scotia are thought to have been severely reduced in extent, relative to their pre-colonial prevalence (Loo & Ives 2003). This combination of a rare or threatened habitat with apparently high substrate specificity and restriction to the extreme western part of the province, suggest that *Homalotheciella subcapillata* may be a species at risk in Nova Scotia and Canada. Conserving and promoting the recovery of old hardwood forests with beech components in the extreme western part of Nova Scotia should be a priority to ensure this species' persistence. Additional survey work is also needed, to further test the apparent range restriction and rarity of *H. subcapillata* throughout the western part of the province.

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FIRST OCCURRENCE OF THE EUROPEAN TERRESTRIAL FLATWORM, *MICROPLANA TERRESTRIS* (MÜLLER OF, 1773) (PLATYHELMINTHES: GEOPLANIDAE), IN MARITIME CANADA

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ABSTRACT

The first Canadian Maritime occurrence of the European terrestrial flatworm, *Microplana terrestris* (Müller OF, 1773), is confirmed via genetic barcoding. *Microplana terrestris* was observed on the soil surface in a rural garden in Tantramar, Westmorland County, New Brunswick, in November 2021, 2022 and 2023. In addition to confirming identity, barcoding also confirmed *M. terrestris* diet at the site included earthworms, *Aporrectodea* sp., and the Common Amber Snail, *Succinea putris* Linnaeus, 1758. Future barcoding efforts should prove to be a useful approach to providing a more detailed understanding of diet in *M. terrestris* and other terrestrial flatworms, and their impact on associated soil fauna. Further reporting of non-native terrestrial flatworms in Canada could perhaps be enhanced through citizen-based science monitoring.

Key Words: *Aporrectodea* sp., citizen science, diet, flatworm, invasive species, *Microplana,* New Brunswick, *Succinea putris*

INTRODUCTION

The introduction and establishment of non-native terrestrial flatworms, usually via the horticultural industry, has raised concerns in many parts of the world (Sluys 2016, Murchie and Justine 2021, Thunnissen *et al.* 2022, Mori *et al.* 2023), including Canada (Justine *et al.* 2019). However, to date there have been few such introductions to eastern Canada. Judd (1957) reported a specimen of *Bipalium kewense* Moseley, 1878 from Ontario (London). Ogren (1991) documented

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Rhynchodemus sylvaticus (Leidy, 1851) from Ontario (Toronto and Belfountain, northwest of Toronto) and *Microplana terrestris* (Müller OF, 1773) from sites in Quebec (Meech Lake) and Ontario (Toronto). Justine *et al.* (2019) reported *Bipalium adventitium* Hyman, 1943 from Canada (Montreal, Quebec) for the first time, with subsequent media reports suggesting the species is now established in both Montreal and Toronto (Landau 2022, Blais 2023). Adl *et al.* (2006) reported on a possibly undescribed *Geocentrophora* sp. collected from forest soils in mostly public parks, near Halifax, Nova Scotia. They also encountered a second species (one individual) that was morphologically identical to *G. baltica*, a species known from northern Europe. Currently, the native versus non-native status of these flatworms in Nova Scotia is unclear.

Many species of terrestrial flatworms feed on earthworms, snails, and other soft-bodied soil invertebrates (Winsor *et al.* 2004) and there is evidence that some species can reduce earthworm populations to the extent this can impact agricultural productivity (Murchie *et al.* 2003). While this is perhaps of less concern in Canada, where most earthworms are of non-native origin (Reynolds 2022), non-native terrestrial flatworms may still have the potential to effect native soil fauna and soil processes in Canada. Where terrestrial flatworms are invasive, lack of information about natural history has made it difficult to assess risk (Thunnissen *et al.* 2022), although *M. terrestris* is apparently mainly a scavenger (Jones, 2005, McDonald and Jones 2013). Winsor *et al.* (2004) notes that the impact of adventive populations of *M. terrestris* are unknown. Here we report the first occurrence of the non-native terrestrial flatworm *M. terrestris* in Maritime Canada.

METHODS

Unidentified flatworms were first noted on the exposed soil surface of a vegetable garden and under pieces of adjacent discarded carpeting at 55 Water Street, Tantramar (former village of Dorchester), Westmorland County, New Brunswick, Canada (45.88865°N 64.51709°W; Fig 1A) in early November 2021. Specimens were collected 14 November 2021, 7 November 2022, and 18 November 2023, killed in 5% ethyl alcohol or very hot water, and stored in 70% ethyl alcohol (voucher [New Brunswick Museum] NBM-GI-11577) or 95% ethyl alcohol (NBM-GI-11726; for barcoding).

Fig 1A **Habitat for *Microplana terrestris* at Tantramar, New Brunswick, Canada. Arrow marks area where flatworms were particularly abundant on the soil surface in November 2021 and 2022.**

Fig 1B ***Microplana terrestris* collected November 2023, Tantramar, New Brunswick, Canada.**

RESULTS

Live flatworms were 15-25 mm in total length and 1-3 mm in width when extended during forward movement over the substrate (Fig 1B). Dorsally, the worms were a uniform dark black in colour and very light grey-white ventrally. A full-length DNA barcode of 549 base-pairs (bp) was generated from sample NBM-GI-11726 using primer cocktail C-LepFoIF_C-LepFoIR. The sequence recovered was a 98.82% match to NCBI (National Centre for Biotechnology Information (NCBI) https://www.ncbi.nlm.nih.gov/) reference records representing *Microplana terrestris.* Additional sequences generated from *M. terrestris* samples collected at Tantramar provide some insight into the diet of *M. terrestris* at the site. A full-length DNA barcode of 658 base-pairs (bp) generated from the sample using primer cocktail C_VF1LFt1/C_VR1LRt1 was a 99.39% match to BOLD (Barcode of Life Data System at www.boldsystems.org/) reference

records representing *Aporrectodea* sp. (Oligochaeta: Lumbricidae), while a full-length DNA barcode of 655 base-pairs (bp) using primer cocktail C-LepFoIF_C-LepFoIR was a 100% match to BOLD reference records representing the Common Amber Snail (*Succinea putris* Linnaeus, 1758).

DISCUSSION

External morphology of flatworms matched the description of *M. terrestris* provided by Ogren (1984). However, Mateos *et al.* (2017) found that a series of samples initially assigned to *M. terrestris* morpho-types fell into different genetic clades. Although *M. terrestris* appears to have a wide distribution in western Europe and Great Britain (Jones 2005, Álvarez-Presas *et al.* 2012), recent investigations (Álvarez-Presas, *et al.* 2022) suggest European populations of *M. terrestris* are a complex of "pseudo-cryptic" species. While our barcode results have identified New Brunswick material as *M. terrestris*, the results can only be as accurate as the reference records available. To ensure accurate identification, and in light of recent phylogenetic work (Sluys *et al.* 2016, Mateos *et al.* 2017, Álvarez-Presas *et al.* 2022), future barcode analyses of North American *Microplana* sp. will need access to a wider range of genetic reference records than may currently be archived.

Microplana terrestris, like most terrestrial flatworms, is reported to be a generalist predator of gastropods, earthworms and small arthropods (Winsor *et al.* 2004). Jennings (1959) lists small earthworms and slugs, injured collembolla, isopods, insect larvae, and myriapods among prey. Our barcode results, a match for *Aporrectodea* sp., and *S. putris*, are clearly among the known prey categories for *M. terrestris* (Winsor et al 2004). However, there seems to be little species-specific data on *M. terrestris* prey. Roy *et al.* (2021) seem to have been the only previous investigators to make use of barcoding to better understand terrestrial flatworm diets. In a proof-of-concept approach for *Obama nungara,* Carbayo, Álverez-Presas, Jones & Riutort, 2016, a South American native, they were able to confirm that where this species is invasive in France it is likely to be a threat to native soil biota. Future barcoding efforts should prove to be a useful approach to providing a more detailed understanding of diet

in *M. terrestris* and other terrestrial flatworms, and their impact on associated soil fauna.

There are, as of yet, few Canadian reports of terrestrial flatworms posted to iNaturalist (see iNaturalist.org) or similar platforms, and in some cases images alone will not be sufficient to confirm species identification (i.e. *Microplana* spp.) Regardless, our report from a single locality may not be a true reflection of the occurrence of *M. terrestris* occurrence in Maritime Canada. Álverez-Presas *et al.* (2022) have noted that *Microplana* sp. are easily overlooked due to small size, occurrence at low density, dull colouration, nocturnal habits, and proclivity to hide under leaf litter and other forest floor debris. Furthermore, they are rarely collected using the extraction methods followed for more widely studied groups of soil organisms. Following the experience of Mori *et al.* (2021) in Italy and elsewhere (Mori *et al.* 2023), further reporting and monitoring of non-native terrestrial flatworms in Canada could perhaps be enhanced through citizen-based science projects.

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DIET AND BIOLOGICAL CHARACTERISTICS OF ATLANTIC TOMCOD OR PUNAMU, *MICROGADUS TOMCOD* (WALBAUM, 1792) IN MINAS BASIN, NOVA SCOTIA

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ABSTRACT

Atlantic tomcod are abundant in the Bay of Fundy, but their diet is unreported for Minas Basin. In this study prey content and biological characteristics of tomcod collected in the Avon River estuary of Minas Basin were examined. Their diet was numerically dominated by the amphipod *Corophium volutator* (Pallas, 1766) (Rate of Occurrence (RO) = 73.2%). Other major prey taxa consumed included *Crangon septemspinosa* Say, 1818 (29.3%), *Gammarus spp.* (19.5%), Polychaeta (14.6%), Portunidae (12.2%), Teleostei (9.8%), Isopoda (7.3%), and Mollusca (3.3%). Of stomachs examined only 8.9% contained unidentifiable prey items. Every tomcod examined except one contained prey and the fullness index (HI) varied between 0.01-5.85%. Both mean total length and total body weight of females was significantly greater than for males (254 mm vs 202 mm; 143 g vs 78 g), and the condition factor (K) of both sexes was similar throughout the sampling period (Mean ± SD; 0.79 ± 0.13). Both mean male and female gonadosomatic index (GSI) increased significantly when approaching the winter spawning period, rising from 1.2 in early October to 11.6 by mid-December. The diversity of prey consumed indicated that tomcod fed opportunistically, but their predominate consumption of *C. volutator* was likely

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linked to the large populations of this amphipod on the intertidal mudflats of Minas Basin.

Keywords: Atlantic tomcod, Bay of Fundy, condition factor, *Corophium volutator*, fullness index, gonadosomatic index.

INTRODUCTION

Atlantic Tomcod *Microgadus tomcod* (Walbaum 1792) are distributed along the northeastern coastline of North America from southern Labrador, Canada, south to Chesapeake Bay, US (Cox 1921, Stewart & Auster 1987), and have two known landlocked, freshwater populations in Grand Lake, Newfoundland and Lac Ste. Jean, Quebec (Scott & Scott 1988). Marine tomcod populations occupy estuarine and shallow inshore habitats but also occur in deeper waters offshore (Peterson *et al.* 1980, Scott & Scott 1988). Within the Bay of Fundy (BoF) tomcod occupy most regions including Passamaquoddy Bay (Peterson *et al.* 1980, Fletcher *et al.* 1982), Cumberland Basin (Salinas 1980, Dadswell *et al.* 1984), Cobequid Bay (Bousfield & Leim 1959), and Minas Basin (Dadswell *et al.* 2020, Dadswell & Rulifson 2021).

The life cycle of marine populations of Atlantic tomcod appears to be similar throughout their range. Tomcod spawn in brackish estuaries and freshwater streams with eggs hatching approximately two months after spawning when the larvae immediately disperse seaward (Peterson *et al.* 1980). Larvae are planktonic and young-of-the-year remain in their natal estuary the summer following birth where retention in the estuary is facilitated by tidal currents (Stewart & Auster 1987). Growth rate of tomcod is greatest in their first year and they may begin reproduction during this period (Salinas & McLaren 1983). Tomcod are determinate spawners, and during reproduction, a single female deposits an average of 20,000 eggs (Range 6000-66,000) depending on her size (Vladykov 1955, Schaner & Sherman 1960). Tomcod can live up to 4 years and grow to a maximum reported length of 38 cm (Scott & Scott 1988). After their first year of life, they often move to bays and coastal waters beyond their natal estuary (Bigelow & Schroeder 1953, Stewart & Auster 1987).

Atlantic tomcod are also known as "frostfish," given their propensity to school in creeks, rivers, and estuaries with the approach of cold weather leading into their winter spawning season (Cox 1921, Scott & Crossman 1973, Fletcher *et al.* 1982). Their ovaries increase as much as nine times in weight from October to December (Schaner

& Sherman 1960). Tomcod spawning season begins in November and continues into February, with peak spawning activity occurring during December to January (Peterson *et al.* 1980, Williams *et al.* 2009). This period of reproductive activity is captured in the Mi'kmaw calendar and denoted Punamujuik'us, which translates to 'spawn of the tomcod' (Kavanaugh *et al.* 2004). In Mi'kma'ki, which encompasses much of Atlantic Canada, including all of Nova Scotia, Mi'kmaw communities have long observed the natural pattern of tomcod migrating upstream to spawn and tomcod have traditionally been accessible to Mi'kmaw harvesters during winter.

The Atlantic tomcod diet has been studied in river and estuary systems of Cobequid Bay and Cumberland Basin (Bousfield & Leim 1959, Salinas 1980, Dadswell *et al.* 1984), and in estuarine areas of New England (Cox 1921, Stewart & Auster 1987). Early planktonic larval stages of tomcod prey almost exclusively on planktonic copepods (Cox 1921), while older benthic life stages feed mainly on crustaceans including amphipods, isopods, mysids, and shrimp in addition to the larvae of shore crabs (Scott & Crossman 1973, Salinas 1980, Stewart & Auster 1987). In Cumberland Basin, the amphipod *Corophium volutator* (Pallas, 1766) was the major prey item (Salinas 1980, Dadswell *et al.* 1984). Upon reaching age one, tomcod have been observed to prey on small inshore fish species including sticklebacks (Gasterosteidae) and the young of other fish, such as striped bass *Morone saxatilis* (Walbaum, 1792), alewife *Alosa pseudoharengus* (Wilson, 1811), American shad *Alosa sapidissima* (Wilson, 1811), and Atlantic herring *Clupea harengus* Linnaeus, 1758 (Cox 1921, Scott & Crossman 1973). In the Miramichi River, New Brunswick, tomcod captured in nets had gorged on rainbow smelt *Osmerus mordax* (Mitchill, 1815) (Hanson & Courtenay 2020). Cannibalistic predation has also been reported (Cox 1921, Scott & Crossman 1973). Understanding the diet of fishes, including that of tomcod, and its influence on growth can be vital to understanding their ecological role and their productive capacity.

Atlantic tomcod are seldom fished commercially (Scott & Scott 1988, Dadswell *et al.* 2020) and it can be challenging to sample large numbers to describe their diet. They are widely distributed in the western Atlantic, but their movement is not well known, and their diet may vary between regions. Habitat variation among populations suggests they have a broad, varied diet but information collected on

their feeding habits in one area may not necessarily apply to others, particularly when compared to other regions of the Bay of Fundy.

Tomcod are important prey for predatory species such as striped bass (Dew & Hecht 1976, Watson 1987) and bald eagle *Haliaeetus leucocephalus* (Linnaeus, 1756) (Reid 1982). Striped bass may selectively target tomcod in summer during times when alternate prey is scarce. Bald eagles target tomcod in early winter when they are aggregated near their spawning sites.

The range of Atlantic tomcod extends into tidal river systems throughout Minas Basin, including the Avon River and adjoining Cogmagun and Halfway Rivers (Fig 1; Dadswell *et al.* 2020), the sites selected to investigate the tomcod diet. Since these tidal rivers are influenced by the tidal forcing of the BoF, they present dynamic foraging challenges to fish during periods of high tidal flow. Like Cumberland Basin (Salinas 1980, Dadswell *et al.* 1984), tomcod is extremely abundant in the turbid nearshore regions of Minas Basin (Dadswell & Rulifson 2021).

To assess the importance of Minas Basin for tomcod, an understanding of their feeding ecology was needed. The objective of this study was to determine tomcod diet and biological characteristics in Minas Basin prior to their spawning period during winter.

METHODS

Study Site Description

Minas Basin (Fig 1) is a unique and dynamic macrotidal marine environment with an average semi-diurnal tidal fluctuation of 16m and a diverse aquatic community (Bousfield & Leim 1959). The large tidal amplitude results in strong tidal currents reaching 4 m/s (Parker *et al.* 2007). The large tides and strong currents cause thorough mixing of marine and inflowing fresh water which results in a complete lack of thermal gradients or haloclines in the Basin.

Summer water temperatures are between 15°C and 20°C and occasionally higher, and winter temperatures drop as low as -1.5°C (Parker *et al.* 2007). These extreme temperature differences are due to the large surface area of the intertidal mudflats that are regularly exposed by the tides. Salinity in the central portion of Minas Basin during summer averages 30 but during winter there is a reduction in freshwater runoff from major rivers which results in less dilution

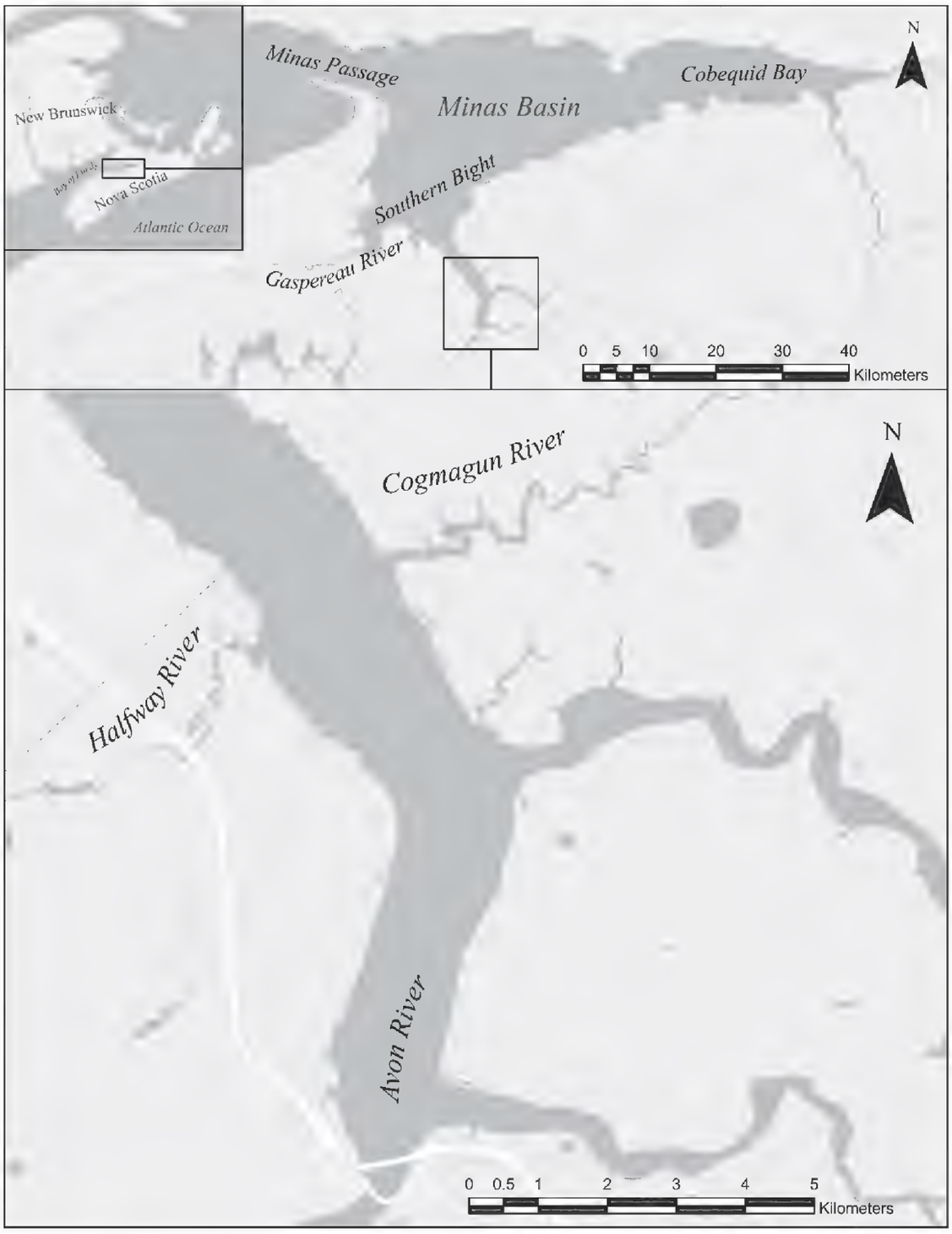

Fig 1 **Map of the Avon River, Nova Scotia (lower) highlighting the three sites (Halfway River, Cogmagun River and Avon River) where Atlantic tomcod were captured for sampling. Inset map (upper) indicates location of sites relative to the Minas Basin and the Canadian Maritimes.**

of the Basin (Bousfield & Leim 1959). Minas Basin is a productive estuarine environment supporting high densities of invertebrates across expansive intertidal mudflats, providing an ideal foraging area for a multitude of resident and migratory species (Hamilton *et al.* 2006, McLean *et al.* 2013, Kendall *et al.* 2018).

Minas Basin is a unique oceanographic extension of the Bay of Fundy as the biota differ substantially. The BoF supports a coldwater fauna, whereas Minas Basin is substantially warmer in the summer and colder in the winter due to its sheltered situation, resulting in a mixture of species categorized as southern, temperate, boreal, Arctic, and European (Bromley & Bleakney 1984). One of the most abundant macro-invertebrates residing in the BoF, the amphipod *C. volutator*, may be found on intertidal mudflats in densities upwards of 10,000 per m^2 (Barbeau *et al.* 2009). *Corophium volutator* serve as an especially important food source for fishes (McCurdy *et al.* 2005, McLean *et al.* 2013) and migratory shorebirds (Hamilton *et al.* 2006).

Sample Collections

To test experimental methods a total of 20 Atlantic tomcod were collected from the Halfway River and Cogmagun River in the Avon estuary of Minas Basin (Fig 1; 45° 04′N, 64° 09′W) during May 2019 using eel pots (Hubert 1996) baited with gaspereau (*Alosa spp.*) and left in the water for 60-90 minutes during the rising tide. Fish were randomly selected for sampling and euthanized using a lethal dose of dissolved anesthetic (Aqualife, tricaine methanesulfonate [TMS or MS-222]) then placed on ice until frozen for preservation on the same day (within a few hours of euthanasia). For stomach contents analysis, fish were allowed to thaw, measured for total length (TL ± 1 mm) and total body weight (BW ± 1 g). Stomachs were extracted then labeled and refrozen until sampling. Sampling was completed under Acadia Animal Care Committee protocol # 07-18R#1A#1.

From September to December 2019, another 157 Atlantic tomcod were collected on an approximately weekly basis from the Halfway River, Cogmagun River and Avon River study sites using baited eel pots. Each tomcod was euthanized on site by means of blunt force trauma (cranial concussion), then placed on ice and returned to the lab for analysis (normally a few hours after euthanasia). Tomcod were measured for TL, BW, and sexed. Stomachs were removed from 110 tomcod and preserved in 70% ethanol to prevent decomposition (Bowen 1996). Sampling was completed under Acadia University Animal Care Committee protocol #10-19.

Diet Analysis

The 20 Atlantic tomcod collected in May 2019 were thawed and used for preliminary sampling. The wet weight of each stomach was

determined to the nearest 1 g. Stomachs were opened and contents spread onto a petri dish using dissection instruments. Items were sorted and identified based on morphological features. Stomach content samples were examined under a dissecting microscope to confirm identification. Prey items were recorded for each stomach on a presence/absence basis and identified to the lowest possible taxonomic level. Enumerating individual prey, however, was not possible due to advanced digestion, rendering it difficult to consistently produce accurate counts (e.g., amphipods may have been identifiable but often whole individuals with all legs/mouth parts intact were not consistently present).

The wet weight of the 110 stomachs collected during fall 2019 were each determined to the nearest 1 g and the total stomach contents were removed and weighed to the nearest 1 g. Gonads were removed from 82 individuals and gonad wet weight (GW) determined to nearest 1 g.

Items observed in the 110 stomachs collected during the fall sampling period were recorded on a presence/absence basis (Bowen 1996). For identification of species and groupings to the lowest possible taxonomic level, a key specific to the fauna found in Minas Basin was used (Bromley & Bleakney 1984). Post-capture digestion may have resulted in loss of dietary information, so, when possible, items were identified based on hard parts remaining, such as bones and otoliths found in stomach samples using a guide (Rojo 2015). Items including fishing bait, plant detritus, soil detritus and unidentifiable contents were also recorded when encountered.

Data Analysis

The percent rate of occurrence (RO) of each prey taxa found in sampled Atlantic tomcod was determined as the total stomachs observed to contain each prey grouping in relation to the total stomachs examined (%). Some prey items were not identified to genus or species level and were combined into a higher taxonomic level based on similarity or close relation (e.g., unidentified crab species and green crab were grouped together in family Portunidae, Table 1). The percent observed RO of prey items was then separated for males and females where sexed individuals were recorded.

A cumulative prey curve was created based on each encounter of each newly identified prey item in chronological order and was used to assess if sample size was sufficient to accurately describe the diet

Table 1 **Taxonomic identification summary of prey encountered in Atlantic tomcod stomachs collected during May-December 2019 in Minas Basin expressed as percent rate of occurrence (%) for male (n = 33), female (n = 57), and combined (n = 123) with undetermined sex (n = 33). Amphipoda* that could not be identified to a lower taxon.**

Prey	Male (%)	Female (%)	Combined (%)
AMPHIPODA*	66.7	75.4	78.1
Corophium volutator	93.9	64.9	73.2
Gammarus spp.	15.2	15.8	19.5
DECAPODA: CRANGONIDAE			
Crangon septemspinosa	27.3	24.6	29.3
PORTUNIDAE	18.2	10.5	12.2
Carcinus maenus	12.1	3.5	7.3
ISOPODA	6.1	7.0	7.3
CEPHALOPODA	3.0	3.5	2.4
BIVALVIA	0.0	1.8	1.6
POLYCHAETA	12.1	15.8	14.6
TELEOSTEI			
Gaspereau (bait)	60.9		
Microgadus tomcod	3.0	7.0	5.7
Alosa aestivalis	3.0	1.8	3.3
Menidia menidia	0.0	1.8	0.8
MAMMALIA: RODENTIA	1.8	0.0	1.8
Unidentified Prey	3.0	10.5	8.9

[a] Also plant detritus - 39.8%, soil detritus - 4.9%, and empty- 0.1%

composition of tomcod. To determine if the cumulative prey curve reached an asymptote, we fitted a straight line to the last 4 points of the curve and compared the slope of this line with a line of slope 0 (Preti *et al.* 2012; Varela *et al.* 2020). The degree of gut fullness was calculated as Hureau's Index (HI) using the equation:

HI (%) = (ingested biomass [g] / total body weight [g]) x 100 (Berg 1979).

Biological characteristics among fish (TL, BW) with an identified sex were compared with one-way ANOVA tests followed by a post-hoc Tukey test if a significant *p*-value was produced. Fish were grouped to compare sexes within and between sampling sites, as well as overall. Biological characteristics of captured tomcod were

also compared for condition factor and their gonadosomatic index. The Fulton condition factor (K) was determined where:

$K = (BW\ [g] / TL^3\ [mm]) \times 100{,}000$ (Anderson & Neuman 1996).

The gonadosomatic index (GSI) was determined where:

GSI = (GW[g] / BW [g]) x 100 (Flores *et al.* 2019).

The condition factor was plotted in relation to date to examine trends during the sampling period and changes over time were tested using one-way ANOVA and a post hoc Turkey's test. The variation in GSI was examined using date as a factor to determine if there were any significant difference between sampling days, and therefore during the sampling period and tested with a one-way ANOVA. If the ANOVA returned a *p*-value of less than 0.05, it was deemed significant, and a post-hoc Turkey's test was performed. Correlation analysis was performed using HI vs GSI to determine if there was a relationship between these variables.

RESULTS

Diet

Of the 177 Atlantic tomcod collected, 123 were suitable for examining dietary items and 110 had stomachs and stomach contents weighed. The cumulative prey curve constructed from the dietary analysis was substantially reduced after 100 stomachs were assessed (Fig 2) and reached an asymptote ($y = 0.3x + 17.5$) that was not significantly different from 0 (T – test; $P = 0.2254$) resulting in a reasonable confidence that a large portion of the overall diet was identified. Only one stomach was empty with no organic or inorganic material present. Mean and standard deviation of gut fullness (HI) across samples was 1.14 ± 1.06% (n = 109) and ranged from 0.01- 5.85%.

Among Atlantic tomcod stomachs examined 92.7% contained prey items. Taxa most frequently ingested by tomcod included *Corophium volutator* (73.2%), sand shrimp *Crangon septemspinosa* Say, 1818 (29.3%) and *Gammarus spp.* (19.5%; Table 1). Amphipods were the major prey class consumed based on occurrence (78.1%), and when comparing males to females, amphipods (including both *C. volutator* and *Gammarus* spp.) were the primary prey class consumed by females (75.4%), while *C. volutator* alone were the primary prey class

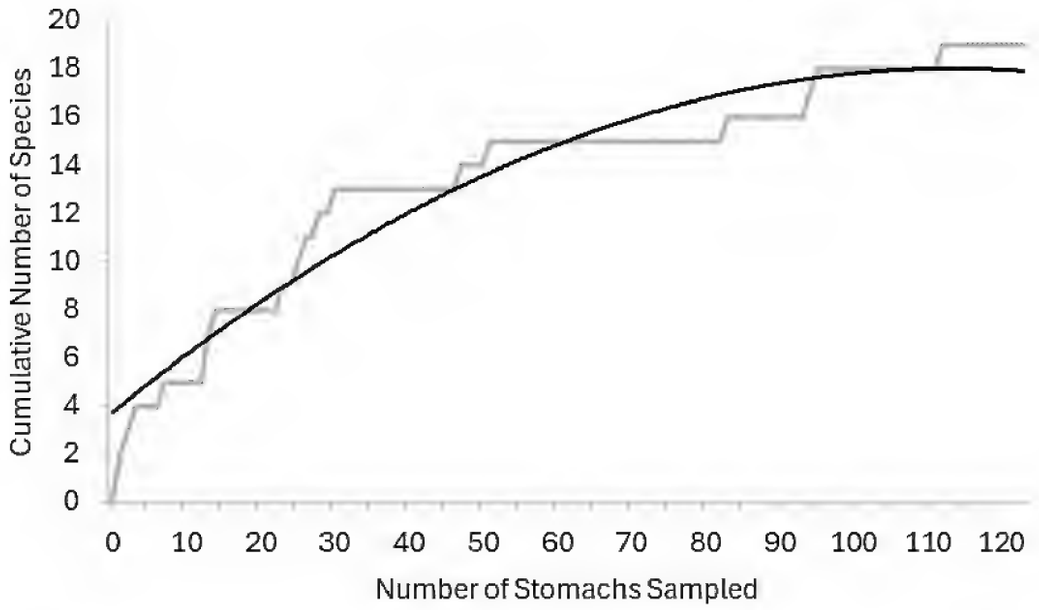

Fig 2 **Cumulative prey curve for Atlantic tomcod diets indicating number of new taxa encountered relative to number of stomachs containing prey (n = 123). The gray line is the increase of prey item values as they were encountered, while the black is a polynomial line calculated from the data with an equation of y = -0.001x2 + 0.243x + 4.032.**

consumed by males (93.9%; Table 1). A few other amphipods were noted but they could not be identified to a lower taxon.

Polychaete worms were present in 14.2% of stomachs examined but they were unable to be identified to a lower taxonomic level due to advanced digestion (Table 1). Crabs (Portunidae) were observed in 12.2% of stomachs examined of which 7.3% were juvenile green crab *Carcinus maenas* (Linnaeus, 1758). The occurrence of isopods in stomachs was low (7.3%) and included *Idotea baltica* (Pallas, 1772), *Idotea phosphorea* (Harger, 1873), *Chiridotea coeca* (Say, 1818), and *Politolana polita* (Stimpson, 1853). Identified fishes included Atlantic tomcod, blueback herring *Alosa aestivalis* (Mitchill, 1815) and Atlantic silverside *Menidia menidia* (Linaeus, 1766). Squid remains were observed, which were probably longfin squid *Doryteuthis pealei* (Lesueur, 1821). There were two observations of bivalve remains, both of which were probably juvenile amethyst gem clam *Gemma gemma* (Totten, 1834). Trace amounts of digested tissues were present in 11 of the stomachs, however, they could not be identified, and they were assessed as gaspereau bait remains. One sample contained the intact rear half of a small rodent, which may have been either a species of mouse or vole based on the colour and type of fur.

Gaspereau used as bait occurred in 60.9% of tomcod stomachs examined (Table 1). Plant detritus was present in 39.8% and soil

detritus in 4.9% of stomachs but amounts were minimal and were mostly accompanied by other items. Only one stomach was completely empty with no organic or inorganic material present. Parasitic Nematoda were observed in 7.3% of stomachs examined but they were not considered to be part of the diet.

Biological Characteristics

Among sampled Atlantic tomcod females were significantly longer (mean TL, 254 mm vs 202 mm) and heavier (mean BW, 143 g vs 78 g) than males (Turkey's test, TL and BW, $P < 0.0001$). The range of TL and BW for all fish from the fall sampling period was, 140-340 mm and 24-342 g, respectively (Table 2). Male and female fish compared for TL and BW between the Avon and Cogmagun River sampling sites were not significantly different (one-way ANOVA). Females had higher mean gonad weight and stomach weight than males (Table 2), but these values were also not significantly different (one-way ANOVA).

The condition factor (K) remained relatively constant throughout the sampling period with a mean ± SD of 0.79 ± 0.13 (Fig 3). Condition factor appeared to decline in relation to fall-winter sampling date but did not demonstrate a particularly strong trend. Although the change in K over time was significant (one-way ANOVA, $F_{13, 53} = 6.39$, $P = 4.67 \times 10^{-7}$), the outcome of a post-hoc Turkey's test indicated that there were no significant differences between results from samples at the beginning and end of the September to December collection period.

Mean GSI of male and female tomcod increased during the fall sampling period by approximately 10 times from 1.2 on 1 October 2019 to 11.6 on 19 December 2019 with one female having a GSI of 24.9 (Fig. 3). Comparing GSI over time for 48 females and 30 males revealed that there was a significant difference between dates of all samples taken (one-way ANOVA, $F_{14, 66} = 6.387$, $P = 7.2 \times 10^{-8}$) and there was a significant difference in GSI between the beginning of the sampling period (1 October to 17 October) and the end (26 November to 19 December; Turkey's test, $P< 0.01$). Correlation analysis indicated there was no relationship between gut fullness (HI) and GSI ($R = 0.12$, $P = 0.4433$).

Table 2 **Mean, standard deviation and range of total length, body weight, gonad weight, and stomach content weight for each sex of Atlantic tomcod collected during September to December 2019 from the Avon and Cogmagun River study sites. Samples from Halfway River were excluded because 19 of the 21 individuals collected were not identified for sex.**

	Total Length (mm) (n = 136)		Body Weight (g) (n = 136)		Gonad Weight (g) (n = 82)		Stomach Weight (g) (n = 110)	
	Male	Female	Male	Female	Male	Female	Male	Female
Avon	(n = 32)	(n = 57)	(n = 32)	(n = 57)	(n = 20)	(n = 35)	(n = 26)	(n = 46)
Mean	199 ± 22	265 ± 34	76 ± 34	149 ± 63	5 ± 3	8 ± 1	1 ± 1	3 ± 2
Range	(170-250)	(210-340)	(141-165)	(62-342)	(0-10)	(0-52)	(0-3)	(1-9)
Cogmagun	(n = 16)	(n = 31)	(n = 16)	(n = 31)	(n = 10)	7 ±5	(n = 17)	
Mean	208 ± 42	235 ± 47	83 ± 44	133 ± 77	7 ±5	12 ±11	2 ± 1	3 ±3
Range	(140-290)	(150-340)	(24-163)	(26-338)	(2-10)	(1-32)	(0-6)	(0-12)

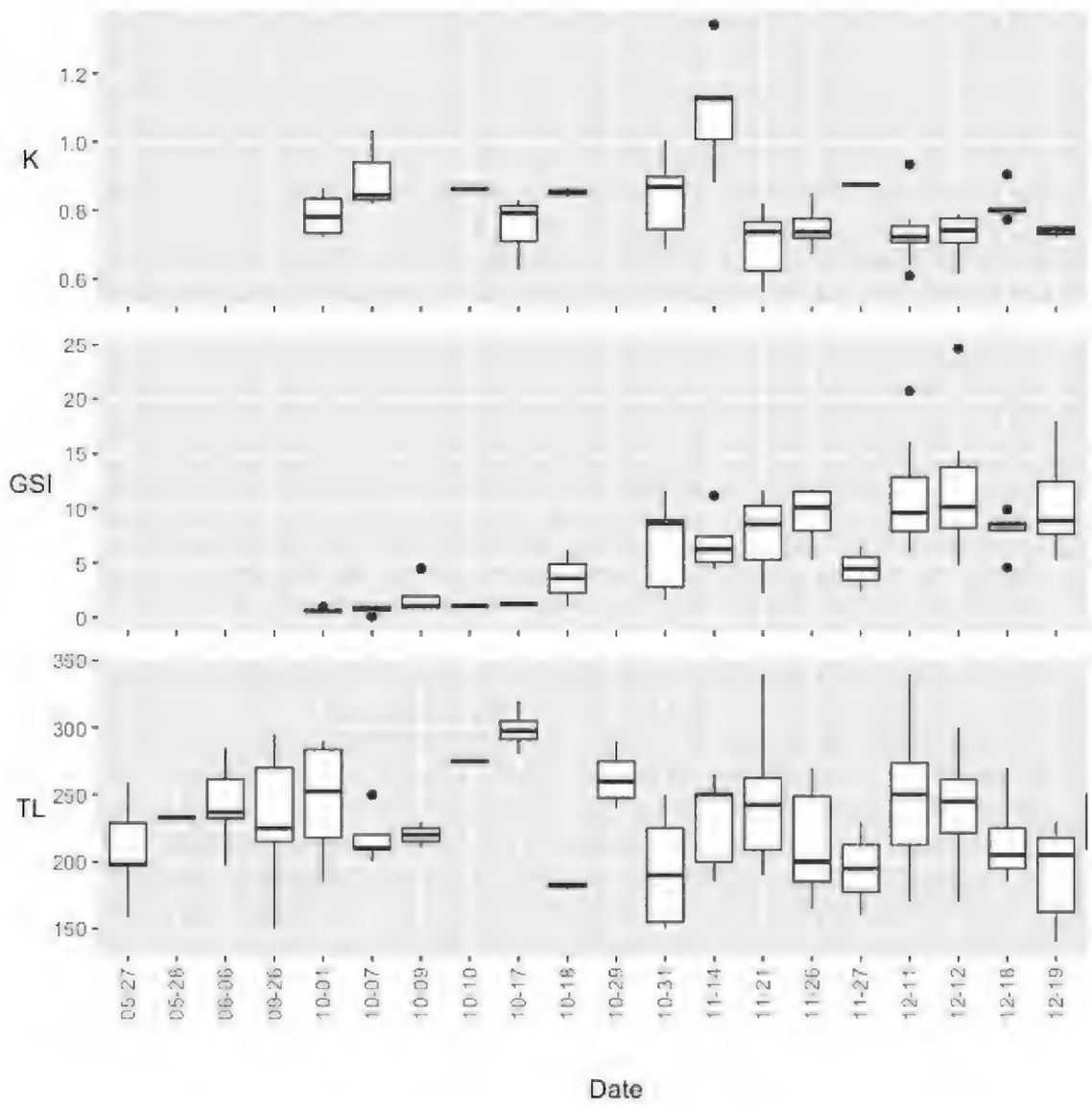

Fig 3 **Condition factor (K), gonadosomatic index (GSI), and total length (TL) distributions for Atlantic tomcod collected during May-December 2019 in the Avon River system of Minas Basin, Nova Scotia. Each box represents the bounds of the 1st and 3rd quartiles; interior dark line is the median, the whisker represents the range, and black dots are outliers.**

DISCUSSION

Stomach contents of Atlantic tomcod were dominated by *Corophium volutator*, an abundant burrow-dwelling amphipod that inhabitants the intertidal mudflats and salt marsh pools in the BoF (Wilson *et al.* 1997, Drolet *et al.* 2013). Tomcod have previously been found to prey on species in direct proportion to their availability and accessibility (Stewart & Auster 1987) suggesting that *C. volutator* are widely available and accessible to benthic feeding tomcod in Minas Basin. *C. volutator* is a key component of the BoF food web and serve as an essential prey item for polychaetes, benthic fish, intertidal

invertebrates, and migratory shorebirds (Dadswell *et al.* 1984, McCurdy *et al.* 2005, Hamilton *et al.* 2006, McLean *et al.* 2013).

The Minas Basin Atlantic tomcod study results agreed with similar diet studies in other estuarine regions which also documented tomcod consuming small crustaceans including amphipods and sand shrimp, molluscs, worms, larval crabs, and fish fry (Cox 1921, Salinas 1980, Stewart & Auster 1987). Tomcod apparently gorge themselves when prey is abundant, which was evident from sampling in Minas Basin where stomach fullness was as much as 5.85% of body weight. Tomcod captured by smelt nets in the Miramichi River estuary (Range 25 - 63 mm TL) had gorged themselves on young rainbow smelt approximately 20 mm long, which was half or more of the length of the tomcod that had consumed them (Hanson & Courtenay 2020).

Percent composition of each prey taxa was used to assess diet in this study largely due to time constraints and the digestion state of some prey. For fishes that feed primarily on large prey items, it is usually possible to count all food items in the stomach, however, these analyses are rendered more difficult for smaller fishes feeding on smaller prey and invertebrates (Bowen 1996). Future studies should ensure immediate and adequate preservation of stomach contents to prevent continued digestion and use 10% buffered formaldehyde for preservation rather than 70% ethanol (Bowen 1996) or evaluate stomach contents immediately upon capture.

Results of the diet analysis revealed that Atlantic tomcod in Minas Basin were predominately opportunistic benthic predators. These findings are supported by their functional anatomy since they possess a wide mouth with an inferior lower lip and an extended upper jaw suitable for obtaining prey from the benthos (Cailliet *et al.* 1986). Estuarine fishes are generally recognized as opportunistic, generalist feeders (Selleslagh & Amara 2015) and the extent of consuming certain prey items often depends on their abundance and availability over time and space (Dolbeth *et al.* 2008, de Carvalho *et al.* 2019). Feeding opportunistically allows a fish to change its diet according to environmental conditions and therefore resource availability. This is a key strategy when feeding grounds may only be periodically accessible due to tidal fluctuation (Selleslagh & Amara 2015).

The intertidal mudflat ecosystem in the inner BoF comprises a simple community structure (Polis 1994, Hamilton *et al.* 2006) with a multitude of species reliant on *C. volutator* as their primary source

of prey (Dadswell *et al.* 1984, McCurdy *et al.* 2005). The health of *C. volutator*, a low trophic-level deposit feeder, possibly links to the overall health of the Minas Basin ecosystem. *Corophium volutator* are reliant on intertidal mudflats for burrowing habitat, so changes occurring in the sediments of the inner BoF could cause changes to their abundance (Shepherd *et al.* 1995). Alterations from eroding sediment structure could include those that result from increased waterflow caused by storm run-off Boates J.S., (2020, pers. comm.) or anthropogenic structures, such as the Windsor Causeway located in the Avon River (Hamilton *et al.* 2006). Following construction in 1970, fine sediment rapidly accumulated around the causeway that was initially unstable and therefore sub-optimal habitat for *C. volutator*, but the intertidal mud flats were eventually colonized by high densities of *C. volutator* (Partridge 2000). Changes in *C. volutator* abundance because of habitat perturbation could cause a bottom-up trophic effect impacting tomcod abundance as well as distribution (Hamilton *et al.* 2006).

Female Atlantic tomcod examined during this study were significantly larger than males for both total length and body weight, and the difference was not site-specific. This was presumed to be unattributed to differences in age, as most tomcod captured in this study were probably between 2 and 4 years of age based on size (Dadswell *et al.* 1984). The mean and range in tomcod total length found in this study (227 mm, 140-340 mm TL) was similar to tomcod taken in an intertidal weir in Minas Basin (211 mm, 35-380 mm TL; Dadswell *et al.* 2020). The slight difference between these two studies is probably the result of the much larger sample size taken during the weir study.

Female tomcod developed heavier gonads than males which may have contributed to their overall weight differential but GSI's were similar between the sexes. Additionally, there was no correlation between gut fullness and gonad size, suggesting that tomcod do not drastically alter their feeding habits to meet the energy demands associated with the growth and development of gonads before spawning. A similar lack of relationship was also observed for tomcod in Cumberland Basin (Salinas & McLaren 1983), however, in that study it could have been a factor of a temporally small sampling window.

A slight decline in the Atlantic tomcod body condition factor was apparent during the fall study period. The change, however, was not

statistically significant. The ten-time increase in GSI found between September to December illustrated the rapid gonad development of tomcod before spawning. But, since there are no other documented condition factor studies that pertain to tomcod, it is difficult to determine if the Minas Basin observation was normal.

This study was the first to examine Atlantic tomcod diet and adult biological characteristics in Minas Basin. Tomcod is apparently an opportunistic predator which targets a wide diversity of prey, especially those with large populations. Any decline of the *C. volutator* population in Minas Basin in the future caused by anthropogenic activities such as climate warming or tidal power development (Hamilton *et al* 2006, Dadswell & Rulifson 2021) could cause trickle down impacts for species such as tomcod by reducing or altering their population and/or habitat usage. Understanding the factors that might influence the abundance of tomcod, both in the present and the future, are key for the conservation of this species. Although no longer fished commercially, tomcod have a food and cultural value for Mi'kmaw communities of Nova Scotia. As well they have a significant ecological value since they could serve as an indicator species for the health of the Minas Basin ecosystem.

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EFFECTIVE MANAGEMENT OF ENDANGERED BLANDING'S TURTLE *(EMYDOIDEA BLANDINGII)* POPULATIONS IN NOVA SCOTIA, CANADA, REQUIRES CONSIDERATION OF THREATS POSED BY LEGACY GOLD MINE CONTAMINATION

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ABSTRACT

The Nova Scotia, Canada, Blanding's turtle (*Emydoidea blandingii*) population is designated as endangered both federally and provincially. Currently, its range is confined to five disjunct sub-populations in the province's southwestern interior. With fewer than 500 breeding adults in the wild, current recovery efforts are focused on reducing mortality risk to adult and juvenile turtles. However, little is being done to address the cumulative impacts of environmental contamination on species fitness and reproductive capacity. This paper focuses on legacy impacts of Nova Scotia's gold mining industry within present-day Blanding's turtle critical habitat, with a focus on mercury and arsenic contamination. To date, previous studies have not considered the impacts of legacy gold mining contaminants on Blanding's turtle recovery and conservation. Three historical gold mining areas were identified as overlapping with Blanding's turtle ranges (West Caledonia District, Brookfield District, and Pleasant River Barrens District). To address the current knowledge gap, site assessments for Blanding's turtle presence, food web contamination surveys, turtle claw tissue sampling, and overall site remediation are recommended to complement existing recovery efforts.

Keywords: Blanding's turtle, critical habitat, environmental contamination, gold mine tailings

INTRODUCTION

Legacy gold mine tailings in Nova Scotia

Large-scale gold mining in Nova Scotia began in the mid-1800's and continued in abundance until the mid-1900's; in that period

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mining districts (Bates 1987, Parsons *et al.* 2012). The primary gold extraction method used involved a mercury-gold amalgamation process, in which extracted and crushed ore-containing host rock would be washed over mercury (Hg) coated copper plates (Parsons *et al.* 2012). Once any present gold was removed, the remaining waste bedrock would then be washed into nearby wetlands as tailings, now significantly contaminated with elemental Hg (Parsons *et al.* 2012). Gold mine tailings are also known to be highly contaminated with arsenic (As), which is commonly found in association with gold ore-containing host rock in Nova Scotia (Drage 2015). Although naturally occurring, the process of crushing and spreading bedrock into surface wetlands allows As to exist in a more mobile, bioavailable form (Lengke *et al.* 2009, Parsons *et al.* 2012).

By the early 1940's, ongoing gold extraction became too difficult and sparse to remain economically viable on a large scale, and the industry became largely dormant (Parsons *et al.* 2012). However, in the past two decades, given the advancement in mining extraction technology, there has been some interest in resuming gold mining activities in the province (Drage 2015). This involves the potential to resume operations at previous mining sites, as well as initiate mining at new sites (Drage 2015).

Despite inactivity at most of the province's historic gold mines for at least 80 years, legacy tailings remain contaminated to the present day (Drage 2015, LeBlanc *et al.* 2020). While As, a known carcinogen, is the primary concern from a human health perspective, Hg, a potent neurotoxin, is also highly dangerous, particularly if methylated into its organic form (O'Driscoll *et al.* 2005, Drage 2015). In this lipophilic form, methylmercury (MeHg) can readily cross the blood-brain barrier in animals, where it is then prone to bioaccumulation and trophic biomagnification (LeBlanc *et al.* 2020). MeHg forms in acidic and anaerobic environments in the presence of methylating sulphate or ferric reducing bacteria (O'Driscoll *et al.* 2005). Such conditions commonly occur within wetlands in Nova Scotia, including those observed at legacy gold mine tailings sites (LeBlanc *et al.* 2020).

Management and mitigation

Most gold mine tailings sites have undergone little to no remediation efforts to date (LeBlanc *et al.* 2020). Since the 1970's, numerous studies have investigated As and Hg concentrations in groundwater,

sediments, and plant and animal tissues, both within the tailings themselves, as well as in adjacent residential areas and wells (Parsons *et al.* 2012, Drage, 2015). Parsons *et al.* (2012) summarized the findings of a 2003-2006 multi-disciplinary investigation of Hg and As concentrations in tailings and sediment samples from 14 Nova Scotian mining districts. Based on their findings, 99% of samples exceeded Canadian Council of Ministers of the Environment (CCME) soil and sediment guidelines for As, while at least 20% exceeded those set for Hg in soils, and 71% exceeded for Hg in sediments (Parsons *et al.* 2012). Current CCME freshwater Interim Sediment Quality Guidelines (ISQG) for the protection of environmental and human health for As and Hg are 5.9 and 0.17 mg/kg, respectively, whereas Probable Effects Levels (PEL) for As and Hg are 17 and 0.486 mg/kg dry weight, respectively (CCME 2023). For soils in residential areas, CCME guidelines for As and Hg are 12 and 6.6 mg/kg dry weight, respectively, representing an integrative Soil Quality Guideline for Human Health (SQGHH) and Environmental Health (SQGE) (CCME 2023).

LeBlanc *et al.* (2020) conducted a review of 23 studies examining Hg and As exposure and bioaccumulation in terrestrial and aquatic organisms from legacy gold mine tailings sites in the province. The review outlines all organism sampling studies conducted at gold mine tailings sites in Nova Scotia to the time of publication, covering a diverse array of plant, invertebrate, fish, amphibian, and mammal species (LeBlanc *et al.* 2020). Overall, the review concluded that organisms found in and around tailings sites typically have Hg and As tissue concentrations elevated above background concentrations typical for individuals from non-contaminated sites, or exceeding CCME tissue consumption guidelines (LeBlanc *et al.* 2020). The authors also noted that there are currently no CCME guidelines regarding safe levels of Hg and As occurrences in animal tissues with respect to wildlife health and wellbeing (LeBlanc *et al.* 2020).

Warning signs regarding high As contamination have been posted on crown land gold mine tailings since the early 2000's, with recommendations for the public to avoid exposure to such sites as much as possible (Parsons *et al.* 2012). Additional water and food As level advisories for adjacent residential areas have been issued since the first recorded occurrences of well water contamination were observed in the 1970's (Parsons *et al.* 2012). Mercury contamination of gold

mine tailings is a concern for human health in areas where fish and seafood may be collected for human consumption (LeBlanc & Halfyard 2010, Parsons *et al.* 2012). These cases are similarly managed with region-specific food advisories and restrictions on fishing or harvesting species of interest within contaminated watersheds (LeBlanc & Halfyard 2010, Parsons *et al.* 2012).

Blanding's Turtle in Nova Scotia

Blanding's Turtle (*Emydoidea blandingii*) is a medium-sized, freshwater species that primarily consumes small aquatic invertebrates, fish, worms, insects, and some plant materials (Rowe 1992). It is long-lived, with a natural life expectancy of 80 years, taking at least 18 years to reach maturity in Nova Scotia (McNeil *et al.* in rev.). As such, the population is susceptible to any increase in adult mortality from anthropogenic activities (*e.g.*, roads) as well as increased juvenile mortality from elevated predator populations (*e.g.*, raccoons), which reduces recruitment of juveniles to breeding adults (Parks Canada 2012, ECCC & Parks Canada 2020).

Nova Scotia's Blanding's turtle population is geographically isolated and genetically distinct from the remainder of the species range (ECCC & Parks Canada 2020). Within the Nova Scotian population, there are currently five identified, genetically distinguishable subpopulations (Congdon *et al.* 2008, COSEWIC 2016). This genetic isolation is largely attributed to significant habitat fragmentation and small population size, with limited movement among the fragments (ECCC & Parks Canada 2020). All five present day subpopulations are found in the southwestern interior of the province; the range of each has been designated Critical Habitat (CH) as outlined in the *Action Plan for Blanding's Turtle (Emydoidea blandingii), Nova Scotia Population, in Canada* (ECCC & Parks Canada 2020). The turtles inhabit a variety of seasonal habitats within their larger range and show significant fidelity to their preferred sites (Parks Canada 2012).

Species conservation efforts

The species was originally assessed as 'Threatened' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 1993 (Parks Canada 2012, ECCC & Parks Canada 2020), predating the establishment of the Species at Risk Act (SARA) in Canada by 10 years (Government of Canada 2019). In 2005 the species' status was

changed to 'Endangered', which it retained after a 2016 re-evaluation by COSEWIC (ECCC & Parks Canada 2020). In 2016 COSEWIC estimated the province's population to exist in a state of ongoing decline, consisting of fewer than 500 mature adults (COSEWIC 2016).

As a federally listed Endangered species under SARA, Nova Scotia Blanding's turtle recovery efforts are the joint responsibility of Environment and Climate Change Canada (ECCC) and Parks Canada where the turtles are found on federal/crown land (ECCC & Parks Canada 2020). Currently, the turtle's presence on federal land is restricted to the Kejimkujik National Park subpopulation (ECCC & Parks Canada 2020). All other turtles found on provincial land are the responsibility of the Nova Scotia Department of Natural Resources and Renewables (DNRR) (DNRR 2020). The Nova Scotia DNRR has also adopted the federal *Action Plan for Blanding's Turtle (Emydoidea blandingii), Nova Scotia Population, in Canada* (hereby referred to as the '*Action Plan*') (ECCC & Parks Canada 2020, DNRR 2020) as well; therefore, the recovery efforts at both provincial and federal levels would be expected to be consistent.

Most of the activities and objectives outlined within the *Action Plan* are designed to address three threats to species' recovery: habitat loss and degradation; accidental mortality of adults; and changes in ecological dynamics (ECCC & Parks Canada 2020). Additional threats identified in the *Action Plan* include pollution and environmental contaminants, including specific references to historical mine sites, for which the impact severity is classified as 'unknown'. Current and planned recovery activities include creating management plans for more developed areas within critical habitat ranges, restoring natural habitat where it has been lost or severely altered, encouraging public reporting of turtle sightings, and constructing protective barriers around nests and nesting sites (ECCC & Parks Canada 2020).

While these activities do address short term threats to species recovery, for example mortality due to vehicular collisions, they do not consider the multi-generational effects that can result from chronic contaminant exposure and failure to recruit juvenile turtles to adulthood (Hopkins 2012, Meyer 2014, Landler 2017, Benjamin *et al.* 2018). Given this lack of attention directed towards facilitating multi-generational success, the *Action Plan's* long-term goal of achieving "...a self-sustaining population of Blanding's turtles in Nova Scotia, over the current range, and to maintain sufficient gene flow to prevent

any single population from becoming genetically isolated" may be unattainable (ECCC & Parks Canada 2020).

Threat posed by environmental contamination

The *Action Plan* does not outline any current or past activities to address the knowledge gap surrounding the impacts of environmental contamination on Blanding's turtles (ECCC & Parks Canada 2020), despite acknowledging that turtles are known to nest within historical mine tailings sites in the province (ECCC & Parks Canada 2020). However, specific mines or mining districts where the turtles have been recorded were not disclosed.

Turtles in general are prone to bioaccumulation of environmental contaminants, including Hg, due to their longevity and trophic level (Hopkins 2012, Slimani *et al.* 2018, Benjamin *et al.* 2018). Turtles are also known to be useful bioindicators of Hg contamination in soils and sediments, presenting a direct relationship between concentrations stored in their keratinized tissues and those found in the environment (Slimani *et al.* 2018). In freshwater turtles, long-term exposure to Hg has been linked to thyroid dysfunction, interference with magnetic geo-orientational capacity, maternal infertility, and reduced hatchling success due to maternal Hg transfer (Hopkins 2012, Meyer 2014, Landler 2017). Aside from the obvious consequences of reduced fecundity and hatchling failure, these health impacts can also hinder turtle growth and development, further reducing overall population fitness (Benjamin *et al.* 2018).

While the impacts of long-term As exposure to turtle health remain largely unknown, the general scientific consensus is that chronic exposure to any toxic trace element causes continuous stress on the animal (Rowe 2014, Zavala-Félix *et al.* 2022). Therefore, long-term exposure to As, in tandem with the other factors contributing to decreased fitness in Blanding's turtles, should also be recognized as a significant threat. No study of Hg or As concentrations in the tissues of turtles or other reptiles in NS gold mine tailings sites has been conducted to date (LeBlanc *et al.* 2020).

MATERIALS AND METHODS

Location data obtained from the *Historical gold mining areas in Nova Scotia* map series (Smith & Goodwin 2009) were used to determine potential for overlap between Blanding's turtle habitat

and legacy gold mine tailings habitat in Nova Scotia. The map series details all 64 historical gold mining districts in the province as aerial photos overlain with property boundaries and the approximate locations of tailings ponds and mine shafts as identified by previous studies and reviews. These maps, created by Smith and Goodwin (2009), were not confirmed by field checks.

Maps of the Western Meguma Group formation from this series show the approximate mining activity areas for six mining districts (West Caledonia, Whiteburne, Molega, Leipsgate, Brookfield, and Pleasant River Barrens) determined most likely to overlap with Blanding's turtle critical habitat; these were georeferenced and digitized using ArcGIS Pro software. Nova Scotia Blanding's turtle critical habitat areas were also georeferenced and digitized from the federal *Action Plan* species overview map (ECCC & Park's Canada 2020). All original figures were generated in ArcGIS Pro using the North American Datum 1983 (NAD83) geodetic reference system and the Universal Transverse Mercator (UTM) Projection, Zone 20. Base layers were obtained from the Government of Nova Scotia's geographic data directory.

RESULTS

Of the six legacy gold mining sites investigated, the Brookfield, Pleasant River Barrens, and West Caledonia mining areas were identified as overlapping with present day Nova Scotia Blanding's turtle critical habitat (Fig 1). The West Caledonia mining area overlaps with a portion of the Kejimkujik turtle population within Queens County, Nova Scotia. Meanwhile, both the Brookfield and Pleasant River Barrens mining areas overlap with the Pleasant River turtle population, in Queens and Lunenburg counties, respectively.

DISCUSSION

Two of the five current Blanding's turtle critical habitat areas in Nova Scotia definitively overlap with three legacy gold mine sites in Nova Scotia (Fig 1). The West Caledonia Mining area overlaps with the only subpopulation currently found on federally designated land in Kejimkujik National Park, while the remaining two legacy sites both overlap with the provincially managed Pleasant River subpopulation.

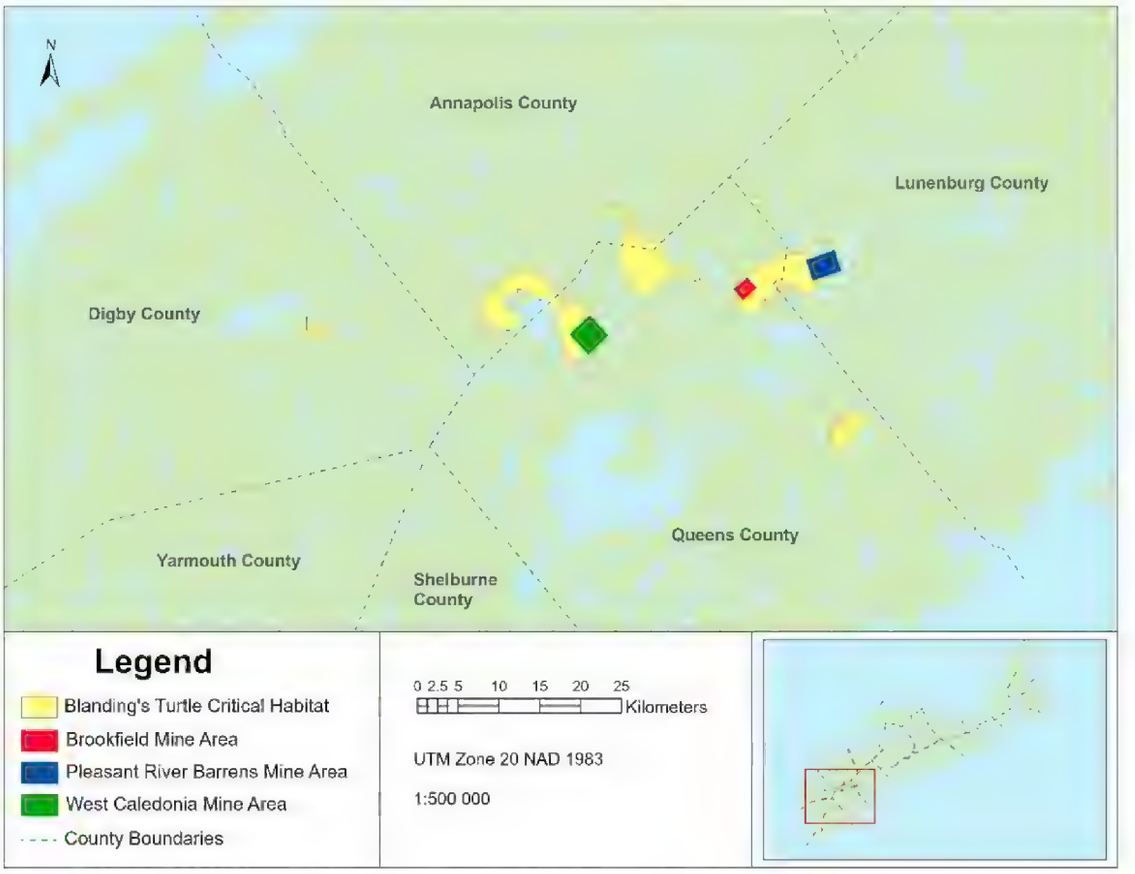

Fig 1 **Three legacy gold mine sites in Nova Scotia that overlap with current Blanding's turtle critical habitat, as digitized from Smith & Goodwin (2009) and ECCC & Parks Canada (2020).**

Therefore, a joint federal-provincial approach, with collaboration from turtle health researchers, would be suitable to investigate and manage the potential for Hg and As contamination in the Nova Scotia population of Blanding's Turtle.

Site level population surveys

To establish the degree of Blanding's turtle presence within the three overlapping mining sites, extensive population surveys should be undertaken. A model for this process is described in the 2012 federal species recovery plan (Parks Canada 2012), and was used to identify and characterize the two new critical habitat ranges in 2015 and 2016 (ECCC & Parks Canada 2020). Techniques employed include visual sightings of individuals, live-trapping, identification of Blanding's turtle nests, and VHF radio-tracking of a subset of juvenile and adult turtles. These activities often engage citizen scientists, in collaboration with Parks Canada, DNRR, the Mersey Tobeatic Research Institute, the Blanding's Turtle Recovery Team, and the Nova Scotia Amphibians and Reptiles Recovery Team (Parks Canada

2012, ECCC & Parks Canada 2020). In recent years GPS-enabled radio-tracking has also been employed; its use would be particularly relevant to any examination of turtle use of former mine sites.

The study should also establish mining area suitability for Blanding's turtle inhabitation based on biophysical characteristics. For the active season (April to September) preferred Blanding's turtle sites in Nova Scotia contain freshwater wetlands characterised by slow moving tannin-rich acidic water, beaver dams, abundant aquatic and overhanging vegetation, and muddy, organic-rich substrate with little rock presence (Congdon *et al.* 2008, Parks Canada 2012). Nesting sites, which are accessed intermittently mainly during June and July, require semi-loose, exposed substrate such as sand, gravel, or soil with large amounts of sun exposure (BTRT 2006, Parks Canada 2012). For the overwintering period from October to March, sites contain deep muddy substrate found within wooded pools, channels, railway trenches, portions of streams or wetlands, and undercut banks (Parks Canada 2012, Canadian Herpetological Society 2023).

Based on site characteristics, further surveys should be conducted during the seasons they are most likely to host Blanding's turtles. Any portions of the mine sites deemed unsuitable for Blanding's turtle habitation in any season could be excluded from further analysis on a site-by-site basis.

Use food web contamination as a proxy for Blanding's turtle health

To establish a precedent for contamination in Blanding's turtles themselves, food web studies investigating Hg and As concentrations should first be conducted as a proxy. Sampling should be done in CH in areas both overlapping and not overlapping mining sites. If such studies confirm significant contamination of the species' food sources, they would support direct sampling of the turtles themselves.

Blanding's turtles are omnivorous, feeding on freshwater and terrestrial invertebrates, small fish, amphibians, and small amounts of vegetation (Rowe 1992, BTRT 2006, ECCC 2020). To date, several studies have examined Hg and As contamination in lower and mid trophic level organisms in Nova Scotia's gold mine tailings sites (LeBlanc & Halfyard 2010, Walker & Grant 2015). Consensus supports elevated levels of contaminants in organisms within and around legacy tailings sites, although with high degrees of variability between sites, media, and organisms examined (LeBlanc *et al.* 2020).

LeBlanc and Halfyard (2010) found elevated As levels in fish from tailings associated lakes compared to those without gold mine tailings in their watersheds. Moriarty *et al.* (2013) found significantly elevated As levels in frogs at a gold tailings contaminated site, which they attributed both to contamination within their diet (mainly consisting of terrestrial invertebrates) and adsorption from water. Eaton and Clair (1985) found that Hg concentrations in fish exceeded Canadian Food Inspection Agency (CFIA) guidelines in over half of their samples. Eaton *et al.* (1978) found significant Hg concentrations in freshwater vegetation, which were also significantly elevated above levels in terrestrial plants at the same site. LeBlanc and Halyard (2010) additionally measured Hg concentrations in fish, with variable results; however, at least one fish per site exceeded CFIA guidelines.

However, CFIA guidelines are designed as metrics for human health risk based on consumption of contaminants, and do not apply to risk for Blanding's Turtle. Given the lack of suitable metric for the latter, the consistent record of elevated As and Hg levels in prey species from different Nova Scotia gold mine tailing sites supports the need for a comprehensive food web study.

Determine Hg and As tissue concentrations in living Blanding's turtles

To establish current contamination levels in living Blanding's turtles, non-lethal tissue samples should be collected from an array of individuals of varying age from locations overlapping and non-overlapping with mining areas. This will help to assess the current risk to the population's recovery and inform the urgency and nature of additional conservation efforts required.

Multiple studies of Hg in turtles have confirmed that claw tissue sampling provides reliable samples with no harm to the animals (Hopkins *et al.* 2013a,b, Van Dyke *et al.* 2016, Slimani *et al.* 2018, Benjamin *et al.* 2018). At the time of writing, only one study (Benjamin *et al.* 2018) has quantified Hg levels in Blanding's Turtle. That study, using claw tissue from a population across four wetland sites in Illinois, United States of America, reported significantly lower Hg concentrations in Blanding's Turtle than in other turtle species of similar trophic levels in the area. Further, the authors did not identify any deleterious effects on the population attributable to Hg contamination (Benjamin *et al.* 2018).

Methodology in Benjamin *et al.* (2018) can also provide a model for a Nova Scotian study. Clipping turtle claws is both easy and harmless (Hopkins *et al.* 2013b); clippings reflect cumulative dietary Hg exposure for several months prior to sampling (Benjamin *et al.* 2018). In that study the distal 2-3 mm of three claws were collected from each back foot using dog nail trimmers; turtle size (mass, straight carapace and plastron length) was also recorded (Benjamin *et al.* 2018). The authors specifically selected gravid turtles (confirmed with field x-rays) to characterize the likelihood for maternal Hg transfer to offspring. However, for this proposed study it may be more appropriate to sample turtles of all ages and sexes, to both increase sample size and develop a broader picture of population-wide contamination.

Remediate legacy gold tailings sites while reducing risk to Blanding's Turtle

The crown corporation Build NS is facilitating the remediation projects of historic gold mines on crown land in Nova Scotia (Build NS 2022). Currently, only five mining districts in the Halifax Regional Municipality and Guysborough County have completed Phase 1 & 2 Environmental Site Assessments under this program, with remediation efforts reportedly underway for at least one site since Fall 2022 (Build NS 2022). None of these sites currently targeted for remediation overlap with the range of Blanding's Turtle, which is restricted to the southwestern interior of the province. However, the remediation plans developed for these sites could be used as a proxy for remediation at sites inhabited by Blanding's turtles, with appropriate modifications to address needs specific to preserving turtle health and safety.

A brief review of two Phase 2 ESAs (Gold Brook Lake/Seal Harbour, Mooseland) reveals similar remediation plans (AECOM Canada Ltd. 2022a,b): an initial phase with construction of engineered wetlands near residual tailings ponds to act as 'filters' preventing contaminants from spreading further in the watershed, followed by extensive excavation of 'dry' tailings to be consolidated and stored *in situ* and under a cap on site (AECOM Canada Ltd. 2022a,b). Based on these activities, potential risk to Blanding's Turtle would include accidental mortality from dredging and vehicle collisions. However, such risks can be reduced by restricting activity to seasons when turtles are likely absent from the area; if turtles are identified

within the site while work is underway, all remediation activities can be temporarily halted.

LIMITATIONS

This study does not provide a comprehensive analysis of Blanding's turtle range overlap with legacy gold mining sites in the province. The species is known to travel significant distances between seasonal habitats and to take advantage of newly created nesting sites; because of the latter some individuals may venture out of their traditional ranges. This presents the possibility for individuals to cross into mine sites that do not overlap with currently designated critical habitat.

Additionally, two of the five current critical habitat ranges for the species were also not identified until the mid-2010's, and the *Action Plan* itself identifies current critical habitat ranges as "likely incomplete" (ECCC & Parks Canada 2020). Therefore, it is possible that unidentified Blanding's turtle sub-populations may reside within legacy gold mine areas not identified in this study.

CONCLUSIONS

Current management plans for the Nova Scotia population of Blanding's Turtle do not adequately address potential impacts of environmental contamination on species recovery. To address such impacts, the threats posed must first be quantified through comprehensive study and review, as discussed above. However, successful recovery and conservation of the species will require ongoing, adaptive, and collaborative effort on the part of all involved management bodies. While the authors present a preliminary framework to begin addressing the current knowledge gap, future management of this SARA species will be most successful if shaped by a double-looped system characterised by ongoing scientific study and monitoring.

Declaration of competing interest

The authors declare no competing conflicts of interest.

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Data availability

Data will be made available upon request.

CRediT authorship contribution statement

Brianna L. Bowes: Conceptualization, Methodology, Writing – Original Draft, Writing – Review and Editing. Tony R. Walker: Writing – Review and Editing.

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SOUNDWAVES IN THE NORTH ATLANTIC: DETECTING THE OFFSHORE BATS OF SABLE ISLAND

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ABSTRACT

As Sable Island National Park Reserve approaches a decade of protection under Parks Canada, new data on the island's biodiversity is useful for informing management. An ultrasonic autonomous recording unit was deployed for 15 months over two years (October 5, 2015-January 8, 2017) to quantitatively characterize the presence of bats on Sable Island. A total of 1721 echolocation passes were identified across the 32 nights that bats were detected on the island (6.9% of total recording nights). Of the nights that bats were detected, *Lasionycteris noctivagans* (Silver-haired Bat) was present on 65% of nights, *Myotis* species were present on 53% of nights, *Lasiurus borealis* (Eastern Red Bat) was present on 25% of nights, and *Lasiurus cinereus* (Hoary Bat) was present on 6.25% of nights. All recordings were captured between late-September and early-December. Evidence of bat species on Sable Island, whether deliberately stopping during migration or brought there by external factors such as weather, highlights that the island may be more important for bats than previously thought.

Keywords: bats, bioacoustics, migration, monitoring, Sable Island

INTRODUCTION

Nova Scotia is a permanent home to at least three species of bats and may be a migratory stopover point, or breeding location, for up

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to three more species (Broders *et al.* 2003, Lucas and Hebda 2011). Bat species distributions on mainland Nova Scotia (NS) are reasonably well understood (Broders 2004, ACAP 2015, Segers *et al.* 2013), where three "resident" species (*Myotis lucifugus*, *M. septentrionalis*, and *Perimyotis subflavus*) and three migratory species (*Lasiurus cinereus*, *L. borealis*, and *Lasionycteris noctivagans*) are known to occur. However, records of bats on the offshore Sable Island National Park Reserve (SINPR) are puzzling (Lucas and Hebda 2011) as the island is located 175 km off mainland NS and it lacks trees that would normally provide day-roosts for bats. Indeed, one study reports three species of bats were observed on the island between May and December over a three-year period (Lucas and Hebda 2011). Researchers and other visitors have also observed bats roosting under the eaves of buildings and pieces of wood at Main Station, located in the center of the island (K. Patriquin 2021, pers. obs.).

These observations are of interest as they contradict the long-held assumption that bats follow landscape features, such as coastlines, while migrating (Hatch *et al.* 2013, Eklöf *et al.* 2014). While observations of bats at sea have been recorded as early as the 19th century (Miller 1897, Norton 1930, Peterson 1970, Peterson *et al.* 2014, Hatch *et al.* 2013, Thompson *et al.* 2015, Dowling and O'Dell 2018), records of bats on Sable Island add to increasing evidence that bats may regularly migrate offshore, rather than only occasionally getting blown off course. Such migration behaviour raises concern for potential conflict with offshore wind farms (Sjollema *et al.* 2014, Brabant *et al.* 2021, Lagerveld *et al.* 2021, True *et al.* 2021) and oil platforms (Boshamer and Bekker 2008). Recent observations show a strong correlation between favourable ambient conditions and the detection of bats at sea (Thompson *et al.* 2015, Brabant *et al.* 2021, Lagerveld *et al.* 2021, True *et al.* 2023). Others speculate that bats may be more likely to visit offshore refuges during periods of inclement weather, when strong winds or weather events might be pushing them to sea (Lucas and Hebda 2011).

To gain a better understanding of bat offshore movements, we investigated bat acoustic activity on SINPR. In 2013, Sable Island was established as Canada's 43rd National Park. This designation shifted management priorities to align with Parks Canada's mandate to protect the site's ecological integrity (PCA 2016, GC 2020). Maintaining the integrity of a protected site requires the development

of comprehensive indicators that can be used to track ecological shifts and trends. To this end, a Species at Risk (SAR) assessment for SINPR was completed in 2015 to inform management plans and develop ecological integrity monitoring programs to conserve native species (PCA 2016). The assessment generated a species inventory for SINPR which included 573 species of terrestrial invertebrates, 330 species of birds (including migrants and vagrants), and 230 species of vascular plants. Only two mammal species – wild horses (*Equus ferus caballus*) and grey seals (*Halichoerus grypus*) – were included in the inventory (PCA 2016). No bat species were identified, and thus there is no current inclusion of any bat species in the current SINPR Management Plan (PCA 2019). Accordingly, identifying the extent that bats use SINPR is important for Parks Canada and the fulfillment of their mandate. Understanding where, when, and why bats might visit SINPR will help form inclusive ecological integrity monitoring programs and better support bat habitat as they pass over the North Atlantic.

METHODS

ARUs

Autonomous recording units (ARUs) are durable, weather-proof bioacoustic recording devices that can be used to detect and record ultrasonic sounds. ARUs can be deployed in the field for extended periods of time, making them useful for collecting data in remote locations while simultaneously reducing human disturbance in sensitive habitats (Shonfield and Bayne 2017). In 2015, we deployed an ultrasonic ARU (Wildlife Acoustics Song Meter 2) on SINPR at Main Station, a small cluster of buildings that houses Parks Canada staff and visiting researchers. The ARU was hardwired to a power source to allow it to function continuously for roughly 17 months (October 2015 – January 2017). The microphone was attached to a wire that extended up a small post, roughly 2 meters above the roof of a small warehouse. The ARU was set to record when a minimum of two pulses, each between 2 and 500 milliseconds long, and between 8 and 120 kHz, were detected. This setting covers the frequency range of bats known to be in this region (Table 1) (McBurney and Segers 2021).

Acoustic Analyses

Recordings collected by the ARU were analyzed using the bat auto-identification feature in Kaleidoscope Pro Analysis Software (Wildlife Acoustics 2017). This feature gives an estimated species identification specific to geographical regions (Wildlife Acoustics 2017). The auto-identifications were then manually vetted by K. Doucette to confirm species identification based on the species' characteristic echolocation minimum frequency (Table 1). Unclear or ambiguous recordings were verified by K. Patriquin, L. Phinney (Mersey Tobeatic Research Institute), D. Washinger (Canadian Wildlife Health Cooperative), and J. Segers (Canadian Wildlife Health Cooperative). Given the relatively flat and barren habitat that characterizes SINPR, there were no expected disruptions by landscape in the detection of echolocation calls that occurred near the deployed ARU (Patriquin *et al.* 2003). Other variables from the recording, such as maximum frequency and call duration, were used to discern calls that had similar or overlapping minimum frequencies. If a call could not be identified to the species level, it was assigned to a species group (e.g., *Myotis spp.*) based on shared call characteristics.

Once the species was identified, each "pass" (two or more echolocation pulses fitting the kHz criteria) was then classified as presence of an individual, presence of more than one species, or "buzz" calls. "Buzz" calls are a series of increasingly rapid clicking noises that taper in frequency, that bats often emit as they are closing in on prey (Schnitzler *et al.* 2003, Holderied *et al.* 2005). Noise files, triggered by ultrasonic frequencies in wind and other ambient sounds (e.g., insects), were analyzed (automatically and manually) to confirm no bats were present and then removed from the dataset.

Statistical Analyses

Echolocation passes were aggregated into a presence-absence matrix for each species or species group to determine what days they were present on SINPR. Passes that had more than one individual within the same species were only counted once in the species total count, but recordings that had more than one species were counted in both species' total count. Since bioacoustics monitoring can only identify species but not individuals, each pass was only used as evidence of presence, not as a count of individual bats at a given time.

Table 1 Minimum and maximum frequencies (kHz) used to identify bat species by audio and visual spectrograph analysis in Kaleidoscope Pro (McBurney and Segers 2021).

	Frequency (kHz)	
	Minimum	**Maximum**
Lasiurus cinereus	15	30
Lasionycteris noctivagans	25	30
Lasiurus borealis	30	45
Myotis lucifugus; Myotis septentrionalis	35	110

RESULTS

At least four species of bats (Silver-Haired Bats (*L. noctivagans*), Hoary Bats (*L. cinereus*), Eastern Red Bats (*L. borealis*) and *Myotis spp.*) were detected on SINPR over the recording period. A total of 1721 echolocation passes by bats on 32 nights were recorded. In 2015, passes were detected in October (n = 1501), November (n = 26), and December (n = 4). In 2016, passes were detected in September (n = 2), October (n = 4), November (n = 182), and December (n = 2). Buzz calls were rarely recorded (n = 62). Activity was detected almost entirely around dusk (Fig 1). When bats were detected around dawn, they were not detected earlier in the same night, with one exception. Bats were rarely detected on multiple consecutive nights (but see below).

The occurrence of species was classified as either presence or absence on days where at least one species was detected. *L. noctivagans* were detected the most frequently in both years, present on 22 of 32 nights that bat activity was detected on SINPR. *Myotis spp.* were present on 17 nights across both years, *L. borealis* were present on 8 nights across both years, and *L. cinereus* were detected the least frequently, on only 2 nights in 2016.

Over the study period, five peaks in detection were identified from the presence-absence matrix (Table 2). Peaks were defined as periods during which there was a higher number of echolocation passes (100 passes) or when there was a greater diversity of species detected (3 species). The first peak, from 2015-10-12 to 2015-10-17, had the highest number of passes (n = 1277) of the entire survey period. Of these passes, *L. noctivagans* was detected the most frequently (n = 1230, 96.3%). Both *L. borealis* and *Myotis spp.* were also detected. The second peak, on 2015-10-25, had a high number of passes

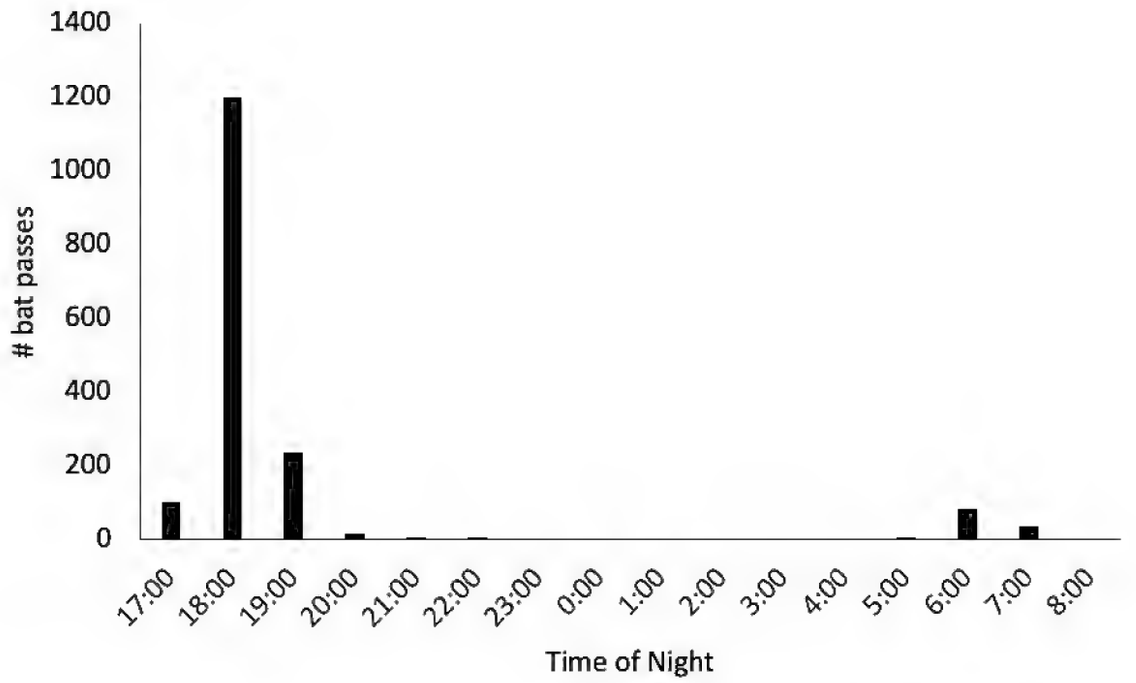

Fig 1 Temporal distribution of echolocation passes detected over the recording period.

(n = 115), but only *L. noctivagans* was detected. The third peak, on 2015-11-30, was the only night that all four species were detected at least once. The fourth peak, on 2016-11-08, had three species detected (*L. noctivagans, L. cinereus, Myotis spp.*). The fifth peak, from 2016-11-14 to 2016-11-15, accounted for most detections in 2016 (n = 135, 71% of the 2016 total), with three species (*L. noctivagans, L. borealis, Myotis spp.*) present.

DISCUSSION

Over the recording period, three long-distance migratory bats (*L. noctivagans, L. cinereus, L. borealis*) and at least one regional migrant (*Myotis spp.*) were detected on SINPR 175 km offshore. Long-distance migrating, non-hibernating bats are characterized by flights of over 1000 kilometers to their wintering grounds (Fleming and Eby 2003, Cryan *et al.* 2004, Sjollema *et al.* 2014), whereas regional migrants, such as *Myotis lucifugus*, typically only travel up to 500 kilometers between summer and winter habitats (Fleming and Eby 2003, Norquay *et al.* 2013).

All detections on SINPR roughly aligned with the end of the autumn migration period, with most detections occurring in October and November. All three migratory bats identified have been known to initiate their fall migrations in mid- to late August into

Table 2 **Presence-absence (1-0) and number of passes (n) for each bat species (LANO, *L. noctivagans*; MYOTIS, *Myotis spp.*; LABO, *L. borealis*; LACI, *L. cinereus*) detected on SINPR by acoustic monitoring. Highlighted rows represent peaks in detection (higher or richer bat presence).**

Peaks in Detection	Date	LANO	n	MYOTIS	n	LABO	n	LACI	n
	2015-10-05	1	53	0	0	0	0	0	0
	2015-10-07	1	25	0	0	0	0	0	0
	2015-10-08	1	14	0	0	0	0	0	0
	2015-10-09	1	1	0	0	0	0	0	0
1	2015-10-12	1	571	1	1	0	0	0	0
1	2015-10-13	1	320	0	0	1	1	0	0
1	2015-10-14	1	114	1	2	0	0	0	0
1	2015-10-15	1	61	1	2	1	1	0	0
1	2015-10-16	1	147	1	5	1	34	0	0
	2015-10-17	1	17	1	1	0	0	0	0
	2015-10-21	0	0	1	1	0	0	0	0
	2015-10-22	0	0	1	1	0	0	0	0
	2015-10-23	1	6	0	0	0	0	0	0
2	2015-10-25	1	115	0	0	0	0	0	0
	2015-10-31	1	7	0	0	0	0	0	0
	2015-11-02	1	2	0	0	0	0	0	0
	2015-11-09	1	1	0	0	0	0	0	0
3	2015-11-10	1	19	1	1	1	1	1	1
	2015-11-22	0	0	1	1	0	0	0	0
	2015-12-12	1	4	0	0	0	0	0	0
	2016-09-22	0	0	1	1	0	0	0	0
	2016-09-24	0	0	1	1	0	0	0	0
	2016-10-05	0	0	1	1	0	0	0	0
	2016-10-11	0	0	0	0	1	1	0	0
	2016-10-23	0	0	1	1	0	0	0	0
	2016-10-24	0	0	0	0	1	1	0	0
	2016-11-06	0	0	1	1	0	0	0	0
4	2016-11-08	1	2	1	3	0	0	1	40
	2016-11-10	1	1	0	0	0	0	0	0
	2016-11-14	0	0	1	1	1	35	0	0
5	2016-11-15	1	5	1	10	1	84	0	0
	2016-12-02	1	2	0	0	0	0	0	0

early October (Lucas and Hebda 2011). No calls were recorded in any other season. This suggests that bats used SINPR as a refuge during their southward movements. However, the reason for their visits remains unknown. Earlier research has suggested that ambient temperature, wind speeds and direction, and barometric pressure are likely to influence offshore bat activity. Some studies propose that bats are likely to be present offshore during calm weather, possibly exploiting mild conditions for foraging (Brabanet *et al.* 2021, Lagerveld *et al.* 2021, True *et al.* 2023), whereas others predict more

occurrences as bats are displaced during inclement weather (Lucas and Hebda 2011).We therefore explore three hypotheses to explain bats on SINPR: bats are being blown northward from further south along their migratory paths, they are being blown eastward and out to sea while moving to their overwintering habitat, or they are actively navigating to Sable Island.

Bats being blown northward

Birds have been known to become entrained in storms during southward autumn migrations and blown back north as storms move into the North Atlantic (McLaren 2012). These storms, including hurricanes and nor'easters, may be similarly affecting bats. An earlier inventory of Nova Scotian bat sightings also reported three species of bats on SINPR as late as November (*L. borealis, L. cinereus*) and December (*L. noctivagans*), suggesting that windward bats may become stranded and seek refuge after being blown off course (Lucas and Hebda 2011).

The timing of bat detections on SINPR parallels the timing of the latter part of the annual hurricane season in the Atlantic Ocean. In 2015, two major storms were recorded in the autumn: Major Hurricane Joaquin (September 28-October 7) and Hurricane Kate (November 8-11) (Stewart 2016). Although neither hurricane passed directly over SINPR, both dissipated over Atlantic waters just south of the island, coming as close as 575 and 680 kilometers, respectively. Hurricane Joaquin occurred in the days leading up to the first peak in detection, while the third peak in detection occurred during Hurricane Kate.

Further research on offshore bats should consider broad weather patterns to explore whether strong storms indeed push bats back up the Atlantic coast. However, the second, fourth and fifth peaks in detection do not temporally correspond to a major Atlantic storm. This suggests that significant oceanic weather events may not entirely explain the presence of bats on SINPR. Additionally, these storms likely do not account for the presence of *Myotis spp.*, as they do not move southward on the same scale. Interestingly, a bat of unknown species was discovered inside one of the buildings at Main Station in January 2024 (D. Kehler, PCA, pers. comm.). During a necropsy, staff at the Canadian Wildlife Health Cooperative (CWHC) determined the bat is not a Canadian bat species (Dr. M. Jones, CWHC, pers. comm). Despite collecting numerous measurements, the bat's

identity currently remains unknown. This appears to corroborate the hypothesis that at least some bats are being blown to SINPR.

Bats being blown seaward

Bats may also be wandering across the North Atlantic under *drift migration*, where they are pushed longitudinally during autumn migrations due to converging air masses (Maunder 1988). This has also been observed in migratory landbirds in Atlantic Canada (McLaren 1981, Lucas and Hebda 2011). Some bats, including lasiurine species, are already known to migrate longitudinally as coastal areas remain mild relative to inland habitats, potentially offering better weather for foraging (Lucas and Hebda 2011, Cryan *et al.* 2014). Drift migration may also help explain the appearance of *Myotis*, which are not expected to make substantial latitudinal migrations.

Bats intentionally moving to Sable Island

Although weather conditions could influence the flights of bats, they may also be using these offshore locales as a rest stop during regular migrations. Insectivorous bats are known to enter torpor at stopover sites during long-distance migrations to conserve energy and may also use a *fly-and-forage* strategy to preserve endogenous fat (McGuire *et al.* 2011, Jonasson 2017, Lagerveld *et al.* 2021). The threshold for insect activity to generally allow for foraging is expected to be around 10°C (Reinhold *et al.* 2018). Minimum temperatures on SINPR during the five peaks in detection ranged from 3.3°C to 15.9°C (GC 2022). The minimum temperature remained above 10°C on six of the eleven days included in the peak detections and was between 8.7 and 10°C for another four (GC 2022). The minimum temperature fell to 3.3°C during the third peak in detection; however, the mean daily temperature remained over 10°C during all eleven days (GC 2022). This suggests that insects may have been available, possibly inferring that bats moved to SINPR on purpose to use the *fly-and-forage* strategy before moving further south. Various insects, including moths, have been documented on SINPR (Wright 1989, Lucas and Horn 2020) and could provide a food source for visiting bats. However, bats appeared to forage very rarely on SINPR within the vicinity of the ARU, despite its proximity to the lights at Main Station which would attract common prey items for bats. The proportion of passes that included buzz calls was low throughout the study period, appearing in only 3.7% of the total passes.

Additionally, buzzes cannot be confidently identified as successful foraging events. Although some individuals may have taken advantage of the opportunity to feed, we speculate that foraging does not appear to be a main driver for bats moving to SINPR.

If SINPR was a routine stopping point, there would also likely be more consistency in detections across years and species. Admittedly, bat activity varies considerably across nights, even in regularly used areas (Hayes 1997). However, the irregular appearance of hoary bats suggests that they are not seeking out SINPR as part of their typical migratory route. Also, the significant difference in detections between the two years (2015, n = 1531; 2016, n = 190) suggests there may have been some underlying event, climatic or otherwise, that drove bats to SINPR (but see below for limitations).

Another potential cause for bats to actively head to SINPR is the presence of lights at Main Station. Though bats typically use echolocation to navigate, they may also use visual cues, such as lights, landscapes, and stars, to navigate while over the open ocean (Hatch *et al.* 2013, Eklöf *et al.* 2014, Brabant *et al.* 2021). There are several lights installed at Main Station that stay on throughout the night, as well as red lights at both East and West Light. Bats may use these lights as beacons to navigate to buildings that can provide refuge before continuing their journey south. Although it may be possible that bats could be taking advantage of foraging opportunities while on SINPR, it seems unlikely they would purposefully travel 175 km to do so. In fact, evidence that most activity occurred around dusk and rarely throughout the night or into dawn may suggest bats were leaving the island soon after arriving (or moving elsewhere on the island). Instead, it is more likely they were blown off course, either during their migrations south or eastward during longitudinal movements to hibernacula.

Limitations & Further Research

The data in this study were collected by one ARU deployed in one location on SINPR. That said, the ARU was deployed at Main Station, where the concentration of buildings provides roosting opportunities that are otherwise lacking due to the absence of trees. It is also lit throughout the night which would attract moths. As such, activity would likely be highest at this location. Nevertheless, deploying ARUs at different points across the island where other structures occur would provide a more comprehensive data set. Including structures

that do not remain lit year-round may also provide insights on the light sources at Main Station acting as an attractive beacon to passing bats. Using acoustic monitoring to detect species also has inherent limitations (Gibb *et al.* 2018). For example (or most notably), number of individuals cannot be inferred from detections; only presence or absence of the species on a given day. For instance, the majority of the 2015 detections are attributed to *L. noctivagans* within a 5-day timespan. It is possible a single bat was responsible for this activity, or several bats may have been present at the same time. Multiple detectors across the island could help determine if multiple individuals make use of the island. Additionally, the microphones in ARUs are subject to deterioration with use (Turgeon *et al.* 2017). As the ARU was not serviced during its deployment, it may have experienced a decline in sensitivity which may have led to a detection bias between the beginning of the study period and the end.

Weather, including continental patterns to the north, west, and from the southwest, should also be considered in further research to determine if sustained trends or anomalies could be used to predict when bats are more likely to be detected at offshore sites. Previous studies have used air temperature, wind speed, and barometric pressure to investigate which weather variables may affect bats (Sjollema *et al.* 2014, Brabant *et al.* 2021, Lagerveld *et al.* 2021). Atmospheric winds (streamlines) have also been used to study the effect on bird migrations (McLaren 1981, Lucas and Hebda 2011). Examining these streamlines at the altitude of migratory bats may help account for abnormal wind fluctuations that could blow migrating bats off course.

Management

To better support bats during the autumn migration, Parks Canada and other staff on SINPR could help prepare for their arrival by ensuring appropriate species-specific roosting sites are available, including bat boxes designed to support cavity and foliage roosting bats (Holroyd *et al.* 2023). As SINPR considers Dark Sky Preserve designation, managers should consider the impact that the criteria may have on bats that might be using the light sources as a navigational beacon. From this study, no conclusive statements can be made that SINPR is a regular part of bats' migratory paths; however, the recurring presence of bats over two years, as well as the previous observations reported by Lucas and Hebda (2011), indicates that bats use SINPR to some extent.

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STUDENT PAPERS

SCIENTIFIC RESEARCH IN NOVA SCOTIA

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INTRODUCTION

On the evening of Monday, March 4, 2024, the Nova Scotian Institute of Science (NSIS) held a student symposium as part of its public lecture series. This year's theme was *Scientific Research in Nova Scotia,* welcoming talks from all scientific disciplines. One goal was to highlight the diversity and breadth of research currently being conducted by students across the province. The NSIS Council therefore decided, as part of its lecture series, to invite short, 3-minute talks from students with projects at any stage of completion. The focus was to attract young researchers to contribute more to NSIS activities. The limited time enabled the session to maximize the number of presenters. Many strong applications to present were received, and eight students were selected from various academic levels (from undergraduates to doctoral students) to give talks about their research. They also answered questions from the live audience and those watching and listening online. At the end of the evening, awards were presented to selected contributors, and all students were commended for very well-presented and interesting talks. The abstracts for the talks are provided below.

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ABSTRACTS

"BEST TALK" AWARD

Sana Salehi, Dalhousie University

The Impact of Precipitation Phase on Changing Groundwater Recharge in Mountain Regions of Canada and the US

Groundwater in alpine regions plays an essential role in downstream water supply. As the climate warms, mountain water resources are under threat with reduced snowpack and glacier recession negatively impacting summer streamflow. However, the extent to which such global changes can impact the mechanisms that contribute to groundwater recharge remains poorly understood. This project aims to address the limited spatial and temporal extents of observational studies surrounding the groundwater in mountainous regions, moreover, enhancing our understanding of long-term trends across geographical boundaries. My primary research question is: Does snowmelt or rainfall precipitation dominate mountain groundwater recharge across mountain regions of Canada and the US? My secondary research question is: will a shift towards less snow and more rain impact this groundwater recharge, due to climate change? We will address the research question by analysing a dataset of 171 observation well from mountain regions across Canada and the US. First, we will build on previous work by categorizing each well as rainfall or snowmelt dominated. We will use stepwise multiple linear regression on each group (snow/rain dominated) of wells to identify which watershed attributes (climate, geology, etc.) are associated with positive/negative trends. Then, we will compile new data from nearby weather stations which includes precipitation phase (rain/snow). We will select ~10 wells for detailed correlation analysis between the well hydraulic head data with the precipitation volume/phase to quantify the groundwater recharge sources and infer how future climate change will impact groundwater recharge.

"CROWD FAVOURITE" AWARD

Lauren Kew, Dalhousie University

Reconstructing Changes in the Northwest Atlantic 14C Depth Gradient using Deep Water Gorgonian Corals

Radiocarbon (14C) analysis is an important tool in chemical oceanography. Nuclear bomb testing in the mid 20th century added

artificial 14C to the surface ocean, which is useful for tracking the movement and mixing of water masses. However, 14C data for the Northwest Atlantic are significantly lacking, so proxy records of seawater 14C are needed. A more complete record of past 14C variability could better constrain the changing influence of water masses off eastern Canada, one of the fastest warming regions globally. Bomb-14C reference chronologies are also important for dating materials such as fish otoliths, clams, corals, and sediments. However, the few available bomb-14C chronologies for the Northwest Atlantic do not extend into the early 21st century or are limited by other factors. In this study, we combine time-resolved 14C data from the gorgonin fraction of deep-water gorgonian corals to create an updated bomb-14C reference chronology for the Northwest Atlantic. Gorgonian corals are ideal bio-archives of seawater 14C since they are long-lived and secrete annual growth rings. The gorgonin fraction encodes the 14C signatures of freshly exported organic matter from the marine mixed layer. Preliminary 14C time histories from the organic fraction of corals spanning the late 1950s to 2022 track the known pulse and subsequent decrease in mixed layer bomb-14C activities. Specifically, the 14C values align with in situ surface water 14C data from 1997, 2003, 2012, and 2022. This updated chronology can be used for applications requiring precise dating of natural marine materials over the last several decades.

OTHER PRESENTATIONS

Kameswari Devi Ayyagari, Acadia University

Marine Population Monitoring Using Machine Learning

Oceans will play a crucial role in our efforts to combat the growing climate emergency. Researchers have proposed several strategies to harness greener energy through oceans and use oceans as carbon sinks. However, the risks these strategies might pose to the ocean and marine ecosystem are not well understood. It is imperative that we quickly develop a range of tools to monitor ocean processes and marine ecosystems alongside the technology to deploy these solutions on a large scale into the oceans. Large arrays of inexpensive cameras placed deep underwater coupled with machine learning pipelines to automatically detect, classify, count, and estimate fish populations have the potential to continuously monitor marine ecosystems and help study the impacts of these solutions on the ocean. In this talk, we

discuss the challenges presented by a dark artificially lit underwater video dataset captured 500m below the surface, propose potential solutions to address these challenges, and present results from detecting and classifying 6 species of fish in deep underwater camera data.

Emma-Jean Freeman, Acadia University

Exploring the Phylogenetic Classification of the Freshwater Mussel Nephronaias tempisquensis in Costa Rica

Freshwater mussels (Family: Unionidae) are integral invertebrates within freshwater ecosystems and play a crucial role in nutrient cycling and maintaining water quality. However, bivalves are also one of the most vulnerable animal groups due to climate change and anthropogenic factors such as habitat destruction and pollution. Therefore, monitoring of bivalve population numbers and distribution is imperative as their environments continue to change. However, research on the phylogeny and distribution of freshwater mussels is described as geographically biased as monitoring activities in some parts of the world, including Mesoamerica, are limited. Also, a lack of available molecular sequence data for many Mesoamerican species of freshwater bivalves has limited evolutionary analyses in this group. In 2019, mussels were collected in Guanacaste, Costa Rica and were identified using cox1 DNA barcoding and assessment of morphological characters. These analyses confirmed the identities of *Nephronaias tempisquensis* and invasive *Sinanodonta woodiana*. These specimens were further examined for doubly uniparental inheritance, an uncommon form of mitochondrial DNA inheritance only observed in some bivalves. Finally, phylogenetic analyses of *N. tempisquensis* revealed a close association with the Popenaiadini tribe of freshwater mussels. The project presented here not only expands our knowledge of aquatic diversity in Costa Rica but also aims to provide crucial molecular sequence data currently lacking for Mesoamerican bivalves. This information can be used in future identification efforts and analyses of the molecular evolution of bivalves found in Mesoamerica. Ultimately, these efforts will become increasingly significant as conservation and monitoring strategies are developed to accommodate our changing climate and species evolution in hopes of maintaining the health and diversity of freshwater ecosystems.

Hannah Freeman, Dalhousie University

Determining Effectiveness of Forestry Beneficial Management Practices for Olive-sided Flycatcher, a Species at Risk Bird in Nova Scotia

The Olive-sided Flycatcher (*Contopus cooperi*) is an at-risk migratory landbird that breeds in forests across Nova Scotia. Habitat loss from forestry is the greatest threat to this species in the province, and previous research has found that while OSFL occupy protected spaces (e.g., National Parks, Conservation Areas), these areas are insufficient in recovering this species and that future efforts must shift to include habitat conservation in working forests.

Beneficial Management Practices (BMPs) are practices that aim to reduce environmental harms and are often created and implemented for species-at-risk conservation. A species-specific BMP was developed for OSFL in the context of forest management and recommendations guided by the BMPs were applied in harvesting in Cape Breton.

This study aims to determine the effectiveness of the BMP recommendations through the collection and analysis of acoustic data obtained using autonomous recording units. Past research has displayed that OSFL vocalization rates vary throughout the breeding season and follow a predictive pattern in the case of successful reproduction. By analyzing song rates and utilizing change point analysis to distinguish between breeding stages, we aim to identify whether OSFL were able to reproduce successfully given harvesting with BMP recommendations.

This project will provide insight into the effectiveness of forestry BMPs in mitigating the impact on OSFL in Nova Scotia by assessing how they influence OSFL presence and reproductive activity. The results will allow us to better advise future forest harvesting practices in the province to consider the conservation of habitat for OSFL.

Shubhangi Mahato, Dalhousie University

Identifying Dairy Cow Biometrics Using AI and Data Analysis

In the domain of dairy farming, the accurate identification of individual cows plays a crucial role in improving herd management, disease control, and overall productivity. Conventional methods like RFID tags, ear tags, and microchipping, although widely used, face

several issues, including high costs, the risk of loss or displacement, and potential harm to both animals and handlers. With the emergence of precision livestock farming, there is a need for a more effective and humane approach to animal identification. Biometric recognition not only ensures accuracy, but also provides high security. This thesis proposes an innovative solution that leverages Artificial Intelligence (AI) and data analytics to address these challenges using advanced biometric techniques. The research presents an AI-based system employing machine learning algorithms to analyse images and videos of dairy cows, offering a more sophisticated and efficient method for identification. The objective extends beyond merely identifying cows; it includes distinguishing between cows of different breeds, ages, and genders. The primary methodologies include Local Binary Pattern (LBP) and Weber Local Descriptor (WLD) for robust feature extraction. To find the best way to recognize each cow, we'll compare different methods. We'll look at different computer programs, like k-Nearest Neighbors (KNN), Decision Tree, Support Vector Machine (SVM), and Neural Network. Each program helps the system work well in various situations and with different information.

Crystal Parker, Dalhousie University

The Intersection of Security and Mobile Games: A Preliminary Investigation of Publicly Available Security Tools for the Analysis of Android Mobile Games

Although users generally might not consider security when they install mobile games on their devices, the potential presence of malware introduces a significant risk. Solutions to guard against this risk exist, such as Google Play Protect and consumer security tools. The goal of this research study is to explore publicly available security tools to analyze Android mobile games to understand if they have suspicious behaviours that might indicate the existence of vulnerabilities and/or malware. The approach involves using publicly available datasets and tools to automate testing of malware on Android games. The publicly available tool VirusTotal is used as it aggregates results from over 70 malware detection systems and includes well-known commercial products, allowing simultaneous testing with multiple tools. The chosen dataset is CICAndMal2017, including 427 malware and 558 benign APK files that are tested with VirusTotal. Fifty-one Android mobile games were also tested. Analysis identifies ten

reliable and nine less reliable tools in VirusTotal's toolset. The game dataset is further tested with three consumer tools: Kaspersky Antivirus & VPN, Avira Security, and McAfee Security. Eight games are found with suspicious results, one tagged as malicious by two tools in VirusTotal's testing set, one labeled as Adware by Kaspersky, and six more exhibiting suspicious activities. This study underscores the essential need for vigilance against malware in mobile games and emphasizes the importance of discerning trustworthy tools in the detection of potential threats.

Sarah Young-Veenstra, Saint Mary's University

Why Don't All Sticklebacks Live in Freshwater? The Role of Early Life Freshwater Tolerance

Freshwater and saltwater are vastly different environments that create opposing pressure and salinity profiles. Coping with the consequent osmotic gradients necessitates physiological strategies that are specific to freshwater or saltwater; these strategies directly oppose one another. Only 3% of fish species, termed "euryhaline fishes", are capable of surviving in both freshwater and saltwater. Within the Gasterosteidae family of fishes, commonly known as sticklebacks, euryhaline capabilities have evolved multiple times, resulting in several closely related species that differ in freshwater tolerance capabilities. The threespine and fourspine sticklebacks (*Gasterosteus aculeatus* and *Apeltes quadracus*) routinely inhabit both freshwater and saltwater, while the blackspotted stickleback (*Gasterosteus wheatlandi*) and white threespine ecotype (*Gasterosteus aculeatus)* are largely restricted to saltwater habitats, despite being able to survive acute freshwater exposure as adults. In my Master's thesis, I investigated whether distribution into freshwater may be limited by stickleback species' capacity to tolerate freshwater during vulnerable early life stages. As proxies to indicate tolerance capacity, I measured fertilization rates, survivorship rates, embryonic metabolic rates, and development rates from fertilization to hatch. I found the non-colonizing blackspotted stickleback had a fertilization success rate of only 25% in freshwater, which may prove a reproductive barrier that limits this species from colonizing freshwater. However, once fertilized, all four species had similarly high survivorship rates (~100%), physiologically sound metabolic rates (150-250umolO2/um), and normal development

rates, suggesting that early life freshwater tolerance does not limit the distribution patterns in these stickleback species.

SUMMARY

Despite the short allotted time, all students gave informative and entertaining presentations. After a challenging deliberation, a panel of NSIS Council judges awarded Sana Salehi, from Dalhousie University, the award for Best Talk for the presentation titled "The impact of precipitation phase on changing groundwater recharge in mountain regions of Canada and the US". Lauren Kew, also from Dalhousie University, won the audience vote for Crowd Favourite for the presentation titled "Updated Northwest Atlantic Bomb-14C Reference Chronology to the Year 2022 from Deep-Water Gorgonian Corals".

Proceedings of the Nova Scotian Institute of Science (2024)
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BOOK REVIEWS

Contested Waters: The Struggle for Rights and Reconcilliation in the Atlantic Fishery. Williams, R. & Wien, F. (Ed.). Nimbus Publishing Limited.

Contested Waters: The Struggle for Rights and Reconciliation in the Atlantic Fishery is a well-intentioned primer on the complex historical and contemporary issues surrounding the relationship between Indigenous Peoples in Canada, non-Indigenous Canadians and the federal government, contextualized through a fisheries-specific lens. This book describes the violent 2020 Lobster Dispute in Nova Scotia, the enduring legacy of intersectional colonial injustice in Canada that dates back to European contact, and potential pathways toward resolution.

The editors, Richard Williams and Frederick Wien, employ a diverse array of voices to elucidate the intricacies of the Atlantic fishery, rendering it accessible to both specialists and general readers. Their objectives are clearly defined: incorporating interdisciplinary perspectives while also acknowledging Canada's historical shortcomings in upholding its commitment to a Nation-to-Nation relationship with Indigenous Peoples.

The book begins by providing historical context for conflicts involving Indigenous and non-Indigenous harvesters in Mi'kma'ki and spotlighting the systemic injustices long faced by Indigenous Peoples in the Atlantic fishery. Furthermore, it comments on ongoing issues pertaining to governance, management, and Treaty Rights implementation related to harvesting.

Contested Waters is divided into six sections that include an examination of the evolution of First Nations fisheries, the Nova Scotia lobster fishery, and the Marshall Decisions. It strives to underline the complexities of the fishing industry, regional governance, and the legal implications of the R vs. Marshall 1999 case. As such, the book excels in providing an introductory understanding of a centuries-long tumult and seeks to offer insights from a diverse group of contributors. These include Indigenous leaders, non-Indigenous industry groups, academic researchers, and legal experts. This account successfully sheds light on the previously normalized subjugation and abuse of Indigenous Peoples, demanding change from the Canadian government at regional and national levels.

However, *Contested Waters* is not without its shortcomings. It occasionally treats Indigenous perspectives hierarchically, positioning them as secondary to settler voices and attributing colonial racism and inequities solely to the complexity of fisheries management. The book concludes with a proposal for a pathway to a more equitable governance landscape for Indigenous harvesters which is primarily voiced by non-Indigenous observers. It tends to scapegoat the colonial structures that perpetuate injustices as a byproduct of complexities within the fishing industry. However, injustices abound across Canada in places far from fishing grounds. Potentially most problematic is that the solutions proposed often prioritize settler interventions over Indigenous self-determination.

With clear objectives, interdisciplinary perspectives, and recognition of Canada's failures to uphold a Nation-to-Nation relationship with the Indigenous Peoples of Turtle Island, *Contested Waters* succeeds in many of its goals. It serves as a call to action, highlighting the urgent need to address contemporary injustices and prevent further inequity. Nevertheless, it falls short in fully acknowledging the root causes of these issues and prioritizing Indigenous voices in the search for solutions. This book is a crucial starting point for discussions on Truth and Reconciliation in fisheries, but should be complemented with greater Indigenous participation and representation regarding pathways forward.

Acknowledgements I'd like to express my gratitude to the teaching staff of the Dalhousie Marine Management Program, particularly Dr. Megan Bailey and PhD Candidate Kayla Hamelin, for their role in inspiring this book review. I'd also like to extend my thanks to the various guest speakers who contributed to my education during Fisheries Management and the Equity Imperative. I'd also like to take this opportunity to acknowledge that the learning and writing process leading to the creation of this document took place on Mi'kma'ki, the ancestral and unceded territory of the Mi'kmaq People. This territory is covered by the Treaties of Peace and Friendship, first signed by Mi'kmaq and Wolastoqiyik Peoples and the British Crown in 1725. We are all Treaty People.

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***An Abundance of Curiosities: The Natural History of North Caronlina's Coastal Plain.* By Edric G. Bolan and James F. Parnell. The University of Georgia Press, Athens Georgia, USA. ISBN 9780820361765, Hardbound, 323 p.**

This a wonderful book for any Atlantic Canada Naturalist to add to their bookshelf. It is not a light read because it is well bound and printed on thick high-quality paper. Each chapter has outstanding colour illustrations. In this review, I can only touch on a few of the "curiosities'.

The book begins with a description of the area and details of the naturalists who documented the treasures to be found in North Carolina. Its not simply a list but an account of each Naturalist, his/her life and their achievements. It starts with john White who made his first visit in 1585 and includes Rachel Carson who did surveys in the late 1930s. In between, we have details of another ten or so naturalists including Alexander Wilson who captured a living ivory billed woodpecker in the province whose cries sounded like a baby in distress and which upset those in the hotel where he was staying. Unfortunately, the bird is now extinct in both North Carolina and the world.

The second chapter deals with the beaches, dunes, and barrier Islands. Those of us who live in Nova Scotia will find much to compare with respect to the issues faced. For example, the commentary on the feral horses of the islands reminds us of Sable Island. Authorities in Carolina also face the problem of management of horse numbers to ensure their survival but avoid over exploitation by them of available grasses and other vegetation. This can lead to destruction of the sand dunes that protect island from the sea. There are descriptions and illustrations of the succession from the seashore and dunes to the windswept maritime forests, along with accounts of the fauna to be found. For example there are fascinating details of the birds to be found in these areas or which visit as part of their migration.

The third chapter, on the coastal marshes, is full of information about the flora and fauna, of this habitat including invasive species. There is an explanation as to the origin of "as thin as a rail" and the strange habits of these birds and marsh rabbits who swim well and can float almost entirely submerged. As might be expected the next chapter covers rivers and estuaries and underlines the impact of human activities on the associated woodlands; that are still being

harvested to produce wood pellets for shipping abroad, or on the effects of dams on downstream areas where endangered species of sturgeon, shad and bass live.

Chapter five, on Interior wetlands, is where we learn about "the Dismal Swamp", once covering a million acres of which only about a third remains today. A range of ferns, orchids, and shrews along occur there and the wetlands are also an important habitat for migrating songbirds, particularly warblers which makes the interior wetlands of great interest to ornithologists. In addition, information on several of the large lakes and the evolved invertebrate and fish species leads next to a discussion about Red Wolves that are to be found in the province. After much research and attempted management, the latest data indicates that Red Wolves are a "good species" that separated from Coyotes some 55,000 years ago and they also lack a close relationship to Gray Wolves. However, to date a new strategy to maintain populations of the Red Wolves in North Carolina by further management has not been implemented,

The penultimate chapter is on the coastal uplands where large Long-leaf Pine forests occur that once provided pitch and masts for the Royal Navy. These trees have very large cones and strategies for surviving and regenerating after fire. Oddly enough the list of names, at the end of the book, omits this tree species and its the Latin name. The Longleaf Pine forest hosts wood peckers and the large Fox Squirrel which is gray, has a black head and a white nose, that may make it less easily seen when foraging in woodlands that are frequently subject to fires. The book ends with an "Afterthought" that addresses: what factors cause species extinction? why are some species vulnerable? and why should we care?. The American Endangered Species Act, equivalent to our Species at Risk Act and its associated COSEWIC (Committee on the Status of Endangered Wildlife), has designated seventeen species of plants and twenty four species of animals as endangered in North Carolina. The abundance of curiosities in the state surely cries out for continued and enhanced conservation activities; supported by all those resident in the state. There are many parallels between North Carolina and Atlantic Canada, and this book provides us with much food for thought.

To a classically trained biologist the use of English names for plants and animals rather than Latin ones is a little frustrating as English names vary from country to country. However, the authors help by

providing a list, at the end of the book, of the used English name and the corresponding latin one as well and an "info box" that explains how Latin names are assigned to species. There are 18 other "info boxes", each taking up a page or so, where the title and text are printed on a blue background. Each deals with a particular odd or interesting topic that varies from whales and whaling, to duck hunting, Greenhead flies, wooden ships, the Intracoastal Waterway etc. For the reader to access these, and other matters in the text, an index is required and the lack of an index is an unfortunate omission. Even if preparing a full index was too consuming for the authors, at least a couple of key page numbers could have been added to the English/latin name list. This would help the reader to find the pages that focus on particular animals or plants. Hopefully, any reprint of this book. or second edition, will add a full index which would significantly increase the readers pleasure and ability to compare information between North Carolina and Atlantic Canada.

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Kings of Their Own Ocean. Tuna, Obsession, and the Future of Our Seas. **Karen Pinchin. 2023. Knopf Canada, Penguin Random House Canada, Toronto, ON. 320 pp.**

Karen Pinchin graduated from Columbia Journalism School (Columbia University) with a Master of Arts in Science Journalism. She is an award-winning investigative journalist and a culinary school graduate. Both skills were necessary for the preparation of this superb book on the iconic bluefin tuna, *Thunnus thynnus* (Linnaeus, 1758).

Pinchin aptly describes her book - "It wasn't just a story of one fisherman and a single fish, but a story about the whole world of contested science and corruption, of the miracles and horrors of globalization and its goddamned children: commercialization and the perils of human hubris, in driving a species to its absolute limit even as our warming climate transforms the ocean at a dizzying pace."

The reviews on the book's dustcover are understandably laudable. But refreshingly for a book of this nature, it is described in terms of "pathos", "poetry" and "lyricism", in addition to the more expected "anchored in science and history" and "a masterwork in environmental journalism".

The book begins with an introduction about Captain Al Anderson of Narragansett, Rhode Island, and a juvenile bluefin tagged by him in 2004. This fish was subsequently named Amelia and caught twice, the last time fatally in the Mediterranean. Both Anderson and Amelia play critical roles in this real-life drama. With his experience of tagging largemouth bass, and catch and release charter fishing, Anderson came to the attention of Frank Mather and Frank Carey at the Woods Hole Oceanographic Institution (WHOI) in Woods Hole, Massachusetts, and their Game Fish Tagging Program, an initiative to help determine the movement of highly migratory species such as the bluefin.

Initially there was little demand for the bluefin other than for trophy photos of the giant fish. The international tuna fishing tournaments involving rod and reel at Wedgeport, Nova Scotia were annual events popular in the early to mid-decades of the last century and patronized by the wealthy. In the 1950's and 60's, the increasing demand for bluefin by the Japanese to satisfy their sushi and sashimi requirements catalyzed a rapid increase in fishing effort, including the use of sophisticated purse seiners. The bluefin, well known on both sides of the Atlantic, was soon subjected to overfishing as shown by tagging data and declining fish catches. The much-maligned International Commission for the Conservation of Atlantic Tunas (ICCAT), a Regional Fisheries Management Organization (RFMO) established in 1966, provided a venue for ongoing and often heated scientific "debates" concerning an appropriate management regime for the bluefin. The initial thesis of separate east and west stocks was subsequently disputed by the results of the tagging programs.

The insatiable demand for bluefin was demonstrated by Japan Airlines requirement to fill their return flights from North America with paying cargos. Hence, there were airborne shipments of giant bluefin encased by chipped ice and enclosed in individual wooden coffins. A maximum of four days from capture to sale at the Tsukiji Market in Tokyo helped to ensure a quality product. The well publicized capture of the world record 1,694-pound bluefin by Ken Fraser

off Aulds Cove, Nova Scotia added to the increasing hype associated with the species.

In the Mediterranean, the fishery for bluefin is probably the world's oldest and intensively organized fishing industry, based on paleolithic cave evidence. The Mercamadrid in Spain is the second largest global fish market, after Tokyo's Tsukiji. The set-up by Spain of the historic almadraba-style net systems following World War II and the use of large fishing vessels to meet the demand for bluefin inevitably led to overfishing. This problem was compounded by corruption and the inadequacies of ICCAT regulations.

Meanwhile in the western Atlantic, Al Anderson encouraged his clients to tag and release their catch and Molly Lutcavage tentatively suggested, on admittedly limited tagging data, that the breeding population in the western Atlantic had declined by 90% since 1975. This caused a furor between the conservationists and fishermen that was compounded by the ecologist and writer Carl Safina's unsuccessful effort to get bluefin listed as endangered by CITES, the Convention on International Trade on Endangered Species. By the late 90's, Molly Lutcavage and Barbara Black, also from WHOI, used better tracking devices (PSAT, Pop-up Satellite Archival Tags). The confirmation by these tags of a trans-Atlantic tuna migration renewed the furor over appropriate management regimes. In September 2007, Lutcavage and team caught Al Anderson's tagged bluefin, which they named Amelia. It was released with a PSAT tag.

In 2008, ICCAT's Scientific Committee recommended a total allowable catch of Atlantic bluefin of 10,000 tons. The estimated catch, including illegals, was estimated to be 60,000 tons. A subsequent paper by Ransom Myers, at Dalhousie University, predicted the collapse of the bluefin population. Condemnation of ICCAT inevitably followed, together with global boycotts catalysed by the World Wildlife Fund and other NGOs. In 2010, CITES again failed to provide protection for the bluefin, a triumph for the commercial industry.

Al Anderson joined the International Gamefish Association in 2015. He had caught and tagged 6000 gamefish, a major contribution to Frank Mather's tagging program. The Mediterranean was rife with illegal fisheries, spurred by Japan's on-going demand that was claimed to consume up to 80% of the global bluefin supply.

In the spring of 2018, Amelia was in the Mediterranean, weighing about 600 pounds and ready to spawn. By late summer, now weak

following spawning, she was heading west towards the Atlantic and was trapped off the Algarve. She was fed mackerel and fattened to about 642 pounds. A scuba diver, using an Italian designed gun, then killed her quickly and humanely. The PSAT tag was returned to the U.S. Sadly, Al Anderson died a few months before Amelia's third and final recapture and death.

The identification of spawning areas in the Gulf of Mexico and the Slope Sea area in the western Atlantic and in the Mediterranean in the east, together with conclusive tagging data that indicated trans-Atlantic migrations in both directions, undermined the two-stock theory. In 2022, an ICCAT meeting in Portugal passed a 3-year Management Procedure Agreement. However, a paper by Ransom Myers and Boris Worm (also from Dalhousie University) estimated that 90% of global fish stocks, including bluefin, could collapse by 2048 if industrial fishing continued at the then present rate. Inevitably, controversy ensued at ICCAT and globally, but perhaps the RFMO was becoming less controversial and more effective.

This book is an exciting, well researched and well-presented story of a beautiful fish species and its fishery. I hope that Karen Pinchin continues her interest in the bluefin and will consider a study of its 1960s fishery in Conception Bay, Newfoundland; the fishery focused on North Lake, Prince Edward Island, where some of the first electronic tags were tested to determine the survivability of the giants following their exhausting, lactic acid generating, rod and reel capture; and the trapnet fishery in St. Margarets Bay, Nova Scotia, where the giants are fattened and now humanely killed, at a time that secures the best price in Japan. The traps, with the support of the fishermen, have provided ideal opportunities for bluefin research.

The author properly extols the beauty of a living bluefin tuna, in contrast to the sight of the dead fish hanging dockside. The book would have accordingly benefitted from an underwater colour photo of a giant tuna, such as was captured by the professional underwater photographer David Doubilet of the National Geographic Magazine, or locally by Gilbert Van Ryckevorsel. One of Gilbert's photographs, for example, taken for the WWF, provided support to get the bluefin into Appendix 1 of CITES CoP 15, giving it the highest level of protection but unfortunately, in the end, being unsuccessful!

I have a final comment on this informative, engrossing and well researched book. We would all like to know of the advances made

to raise bluefin under controlled conditions, initially championed by researchers at Kinki University in Japan; bluefin were netted as juveniles, raised in captivity and where they mated for the first time in 1979. Please Karen, consider a sequel to your wonderful book and also accept a big thank you for writing it! It is highly recommended for all readers with an interest and concern about the ocean and the future of its fauna, most certainly the bluefin, and overall biodiversity.

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NSIS FIELD EXCURSION 2024

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SCATARIE ISLAND EXCURSION

On 14 July 2024, about 20 NSIS members and guests participated in an excursion to Scatarie Island, off the north-east coast of Cape Breton Island. Scatarie is now a protected Wilderness Area, but in the past was populated. It has a distinctive history, geology, ecology, and environment. A previous issue of the PNSIS – Vol. 45, No. 1 (2010) – was devoted to the natural history of the island.

We began at 8:00 am on the dock at Main-à-Dieu, next to the large fishing boat skippered by Robert Parsons. We had chartered the boat to take us to the island, and to come and bring us back at the end of the day. Bruce Hatcher of CBU also brought along a large Zodiac which he used to take groups on a few mini-excursions along the coast of Scatarie.

Before leaving, we heard a little about the history of the island – how it once had a community of 100 or more people with a church

Gathering on the dock.

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Outward bound, Island capped by forest and thick sod.

and a school. They did fishing and limited farming, but gradually the community shrank and in the end the people moved to the mainland. When the island became a protected wilderness area, there ceased to be any permanent residents. But a few families are permitted to make use of their few remaining houses on a casual basis, mostly in the summer.

The day turned out to be finer than the forecast – partly cloudy turning to sunny and quite warm. The seas were very calm, which made for an easy passage. (It is often windy, and choppy with large swells.)

Arriving at the island we disembarked at a sheltered beach at Northwest Cove, using the Zodiac to make the transition from boat to beach. During the day we became fairly adept at getting in and out of the Zodiac without getting our feet very wet. Once on the beach, Jason Loxton gave us a description of the interesting geology of Scatarie. Like much of Nova Scotia, Scatarie Island has a long and complex geological history.

At that point we broke up into a couple of groups. One group went with Maureen Cameron-MacMillan, a Regional Biologist with the NS Dept. of Natural Resources and Renewables, who conducted a guided nature walk. It went through the woods towards the lighthouse on the eastern tip of the island, about 5 km away. Maureen pointed out various native birds and plants, cataloging them. She identi-

A short geology lesson.

fied more than 20 species of birds, some of them just by their calls. One item of interest to the group was a tiny carnivorous plant, Round-leaved Sundew (*Drosera rotundifolia*) growing along the middle of the trail. It's native to Nova Scotia, and it traps and digests small insects in sticky droplets on the red hairs the leaves. This survival strategy allows the plant to thrive in very poor-nutrient soil conditions. This group emerged from the woods on top of a grassy knoll, with a bench, and made their way down to the shore and ate their lunch on some large boulders.

The second group went on a geology mini-excursion back along the coast in the Zodiac. Much of the shoreline was comprised of steep cliffs arranged in upturned layers, and Jason Loxton pointed out many of the interesting features. It is suspected that there may be important fossils to be found, similar to others found in nearby regions, so Jason spent some time ashore examining the strata, but with no luck. But we all enjoyed the spectacular rock formations – and the abundant sea birds. These included guillemots, cormorants, and ducks.

After the geology tour, the Zodiac took this second group around the eastern tip of the island, where sits a decommissioned lighthouse. That structure appears to be quite intact, but some of the surrounding buildings are in a state of collapse. The lighthouse function is now provided a small automatic light in front of the old structure. There also remains a platform where it is believed a foghorn once operated.

Rock hounding, Eastern Harbour backbarrier meadow.

Being on the water as we rounded the tip of the island and passed by scenic rocky outcrops allowed the group to see lots of marine life. Bald eagles were abundant, occupying the roofs of the buildings and the outcrops. Terns flew by in large flocks and roosted on the little islands. And the seals were everywhere – lazing on the rocks, following the Zodiac, or just curiously watching our progress.

The second group disembarked at the beach on the south-east side of the island, where they met some of the walkers, and where we all settled down to have lunch. About half the participants had opted to purchase a "catered lunch" provided by an establishment in Sydney. It was ample and very tasty, with a wide selection of quite healthy items included.

This beach was the last resting place of a fin whale which had washed up a few years ago. We learned that the fin whale is the second-largest species, after the blue whale. This one has been reduced to a bony skeleton and some baleen, somewhat scattered over the beach due to wave action, etc. The backbone was fairly intact – and long – and we found a scapula which was huge, and a rib about 1½ to 2 meters long.

Most of the second group (geology tour and rounding the lighthouse) exchanged places with most of the first group (nature walk),

who embarked on the Zodiac for a trip out to nearby small Hay Island – its main attraction is that it is home to a big seal colony, with a large swarm of seagulls flying around. The group walked up the shore and saw some seal bones and were able to see some seals that were sunning on the rocks from much closer. One even swam quite close to get a look at the people. The group also observed some interesting geological rocks; participants who were interested in them had lots to say about how there were many conflicting rock patterns and how it was difficult to decipher the geological history of the area. Once the Zodiac began the return trip, it went out a bit further east around the Cormandarie Rocks which, until 1949, were the eastern-most extent of Canada. Maureen pointed out some characteristic sea birds, including a Gannet and a Puffin. Then the Zodiac returned around the lighthouse back to the original beach at Northwest Cove.

In the meantime, several of the second group took the path back through the woods to the first beach, while others walked the short remaining distance to the lighthouse before returning. The path was very pleasant, with pretty scenery along the way. There were also large patches of toppled trees and deadfalls. These were the result of Hurricane Fiona, which did extensive damage to that part of Nova Scotia.

Geology cruise, Fin whale backbone and partial jaw.

Refreshments on the return trip, and an end to a great day.

Back at the beach everyone relaxed and waited for Robert Parsons to arrive for the ½-hour return trip to the mainland. A few people even managed a brief swim, saying that the water temperature was quite comfortable – Bruce measured 18.3°C at the surface.

We had a pleasant ride back, enjoying some refreshments. We arrived at about 6:00 pm and the end of a very pleasant and informative day to a little-known and little-visited part of Nova Scotia.

Special thanks should be made of Bruce Hatcher. He suggested this excursion in the first place and then played the major role in planning the trip, and securing the charter boat and the nature guide. He also obtained the excellent catered lunches, and refreshments on the return trip. And he provided and operated the Zodiac, which gave us excellent mini-excursions up and down the coast.

As an addendum, Bruce had also recommended that we consider visiting the Fossil Museum and the adjacent Heritage Centre at Sydney Mines. A few of us did that on the day before the trip to Scatarie and were glad that we did. The small Fossil Museum was especially well-done – with excellent specimens nicely displayed, a logical organization of exhibits, good explanatory signage, and an enthusiastic and knowledgeable guide.

Hank Bird with contributions from
Bruce Hatcher, Donald Forbes and Crystal Parker

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NSIS COUNCIL REPORTS

Reports from the Annual General Meeting
May 6, 2024 - 6:30 pm

AGENDA

163rd ANNUAL GENERAL MEETING

Meeting held in Room S310 Science Bldg.,
Saint Mary's University, Halifax, NS
and at RBC Theatre, Student Culture & Heritage Ctr.,
Cape Breton University, Sydney, NS via Zoom.com

1. Welcome (Stephanie MacQuarrie)
2. **Minutes of Previous AGM:** (S. MacQuarrie)
   Minutes of the 162nd AGM on 29 May 2023
   Motion and Vote to accept the Minutes of the 162nd AGM.
3. **Annual Reports:**
   President (S. MacQuarrie)
   Treasurer (Angelica Silva)
   PNSIS Editor (David Richardson for Peter Wells)
   Membership (Jinshan Xu)
   Library (S. MacQuarrie for Carol Richardson)
   Publicity (Brent Robicheau)
   Website (Romman Muntzar)
   Lecture Programme for 2024-2025 (Alana Pindar)
   Student Science & Technology Communication Competition for 2024 (Jillian Phillips & Jinshan Xu)
   Excursions (Hank Bird)
   Motion and Vote to accept the 10 reports.
4. **Awards:**
   Recognition of new Honorary Member (S. MacQuarrie)
   New Awards & Presentations (Judy MacInnis)
5. **By-Laws & Fees:** (S. MacQuarrie)
   Revisions to the By-laws (Library, Hon. Membership, Terms of Office)
   Motion and Vote to accept amended by-laws.
   Increase in Regular Membership fees.
   Motion and Vote to accept the new Regular Membership fees.

cont'd

6. **Council for 2024-2025:** (S. MacQuarrie)
   Nomination of 2024-2025 Council.
   Motion and Vote to approve the new Council.
7. **Other Business:** (S. MacQuarrie)
   Any Other Business.
8. **Adjournment:** (S. MacQuarrie)

May Public Lecture: Following the AGM, at 7:30pm ADT
Dr. Jason Loxton (CBU) will present "The Geology of the Cabot Trail: The Surprising 1.5-Billion Year Story". The lecture will be presented in-person in Room 203, Shannon Bldg., Cape Breton University. It will also be available via a separate Zoom call.

Council Members & Observers Present: Stephanie MacQuarrie (President), Jillian Phillips (Vice-President and SSTCC),), Angelica Silva (Treasurer),),), Brent Robicheau (Publicity Officer), Alana Pindar (Observer), Hank Bird (Secretary and Excursions), Shannon Ezzat (Councillor), Bruce Hatcher (Councillor), Judy MacInnis (Councillor), Audrey Salinger (Student Rep., SMU), David Richardson (Associate Editor).

Members Present: Patrick Ryall, Carol Morrison, Courtney Strugnell, Don Forbes, Barbara Zielinski.

Regrets & Absent (Council Members & Observers): Peter Wells (Editor), Tamara Franz-Odendaal (Past President, Jinshan Xu (Membership and SSTCC), Romman Muntzar (Webmanager), Tim Fedak (Nova Scotia Museum Observer), Anne Dalziel (Councillor), Adam Brown (Observer, CBU), Jen Sawlor (Observer, Schools), Ale Torres (Student Rep., MSVU).

1. **Welcome**
   (Stephanie MacQuarrie) The President welcomed participants and called the 163rd Annual General Meeting (AGM) to order at 6:30pm. The President noted that presentations would be kept short and informal and that the reports, excluding the minutes from last year's AGM, would be approved as a unit at the end of the presentations. The minutes will include the contents of the slides and additional material from the written Annual Reports.

2. **Approval of the Minutes of the 161st Annual General Meeting of 2 May 2022: (S. MacQuarrie)**
A draft of the 2023 AGM minutes was e-mailed on 19 April 2024 for perusal by all NSIS Members.
There were no revisions to those Minutes.

3. **Motion to accept the minutes of the 161st AGM:**
Moved: by S. MacQuarrie
Seconded: by B. Hatcher
All in favour: Approved unanimously.

4. **President's Annual Report (S. MacQuarrie):**
S. MacQuarrie noted that this was a great year with many changes and accomplishments. She also remarked that it is good that the NSIS is involving other, non-HRM, locations in meetings and lectures. Her remarks focused on Committees and the NSIS-Dal Library relationship.

For the benefit of members, the President provided a current list of the NSIS standing committees and their composition, as follows:

Strategic Planning Committee
Stephanie MacQuarrie - CHAIR
Brent Robicheau (note taker, etc.)
Tamara Franz-Odendaal (past - president)
Hank Bird
Bruce Hatcher

Committee for student symposium and career Q&A session
Jillian Phillips - Chair
Judy MacInnis
Shannon Ezzat
Brent Robicheau
Audrey Salinger
Anne Dalziel
Alana Pindar

Recruitment Committee (make a poster!)
Jillian Phillips
Judy MacInnis

Awards Committee
Judy MacInnis
Brent Robicheau
Peter Wells
Tamara Franz-Odendaal

Editorial Board Committee
Peter Wells
Bruce Hatcher
David Richardson

Student Science Communication Committee
Jillian Phillips
Jinshan Xu

The President also described the changing working relationship between the NSIS and Dalhousie's Killam Library arising from staffing issues and the evolving role of libraries in the digital world. She, with P. Wells, D. Richardson, M. Paon, J. Phillips and H. Bird, worked in collaboration with the staff at the Dalhousie Library, and a number of changes have been made:

- **Librarian Position on Council:** Replace the function with a Councillor to act as "Library Liaison". (Note: requires a change in the By-laws.)
- **Access to the Online PNSIS:** Continues to be available via the Killam Library's website. The 6-month quarantine on new editions for non-members is removed, thus making the PNSIS completely "open access". A banner appears asking that the reader consider joining the NSIS.
- **PNSIS Archives:** We continue to use the Killam Library for archiving and storage of the paper copies of issues of the PNSIS.
- **Mailing of Print Copies of the PNSIS:** NSIS will take over this function as part of the Secretary's role.
- **Exchange Partners:** Continue with the current process. We do not send printed copies of PNSIS to exchange partners, while the Killam Library receives, catalogues, and shelves the few paper copies of journals that are sent to the NSIS.
- **Access Copyright:** We do not receive royalties for the PNSIS or any other publications, and so the Library should not be involved with Access Copyright on our behalf. The NSIS is a

member of A.C. and receives a small distribution of funds to as a result of that membership, so a NSIS Councillor should be responsible for our yearly application.

- **NSIS Mailing Address:** The amount of postal mail to the NSIS is small but important (e.g.: it includes journals from exchange partners) so the Killam Library should continue to be the NSIS mailing address. This involves a few minutes' work per month.
- **Physical Archives of NSIS Records:** The NSIS is transferring them to the Nova Scotia Archives. The NS Archives also has the expertise to assess the desirability, feasibility, and cost of having them digitized.

The President called on other members of Council to present their reports.

5. Treasurer's Annual Report (Angelica Silva):

As of March 31st, 2023, the net worth of the NSIS was $32,902.38, held in our BMO bank account. Of this, $17,902.38 was in cash, and $15,000.00 is in an 18-month GIC paying 4.15% per year, maturing in October 2024.

As of March 31st, 2024, the net worth of the NSIS was $29,348.69, held in our BMO bank account. Of this, $14,348.69 is in cash, and $15,000.00 is the 18-month GIC above.

Revenue from all sources were $6,073.77. $3,168.85 was individual memberships and $150.00 in Institutional Memberships. Payments for the AGM Dinner were $1,065.00. There were $1,302.00 in donations to the NSIS, and there was $387.92 in Income/Access Copyright Royalties.

Expenditures amounted to $9,627.46. This includes $3,386.26 of for production of the ProcNSIS and $1,007.88 for a 170-copy print run of The Birds of Brier Island for the NS Bird Society. Other expenditures included $1,700.00 in Prizes for the SSTCC, $1,253.57 for the venue for the AGM and dinner, $663.00 to support the Sable Island conference and the Fishermen & Scientists Research conference, $1,150.70 for website hosting for 3 years, $100 to support a school Regional Science Fair, and $366.35 for Brochures & Bookmarks and for Publicity &Advertising.

The Treasurer noted that, as of May 2nd, 2022, the NSIS currently has a total of 120 active members and 5 institutional members. (See item #7.)

She thanked Carol Richardson (Dalhousie Killam Library) for her continuing contribution with NSIS mail at Dalhousie University, and for library services. Many thanks to all NSIS Council Members for reviewing monthly reports and suggestions as well as our new Membership Officer J. Xu and to Romman Muntzar that contributed to compiling and transference of membership payments in this past year. Many thanks to NSIS Secretary Hank Bird for multiple roles and contributions with mail and banking.

6. **Editor's Annual Report (Peter Wells & David Richardson):** PNSIS Vol. 53, Part 1, (2023) is on the website, open access. Hard copies from a limited printing await distribution by Carol Richardson of the Killam Library. Some have been distributed by hand or mail locally. As with previous recent Issues, comments on its contents are always welcomed.

Work continues on PNSIS Vol. 53, Part 2, (2024). The draft Table of Contents was updated to guide us. We met on March 27th to discuss our progress. As of late March, two commentaries are complete, with three others invited. Four research articles are completed or being revised. Considerable time has been devoted to the task of finding reviewers and tracking each paper through the review process. Two book reviews are completed and two others are promised. No student papers have yet been received although a summary of the student presentations given at the April lecture is complete. it would be nice to receive some more papers in this category.

The 53-2 Issue underway awaits the inclusion of the completed papers, the May 2024 AGM report, the Editorial, and some more book reviews before it is assembled. We are working with a deadline for submissions for Vol. 53(2) of June 30th, 2024. We welcome more contributions and hope that the Editorial Board and the Council Members will help us in this task. Publication is anticipated for late summer, early Fall, hopefully in time for the first Fall NSIS meeting. A very limited printing is anticipated, to augment the on-line version.

To date, no more papers have been submitted from the Sable Island events of Fall, 2023. There are no plans to chase the organizers or the potential authors. We will consider papers as they are independently submitted. It is the same with the papers being prepared by Dr. Haughian of the NS Natural History Museum; one paper on a moss is completed for the current issue and others may be submitted at a later date.

We did a press run of 170 copies of "The Birds of Brier Island" for the Nova Scotia Bird Society.

We wish to thank the Editorial Board members for their continued service to the NSIS, as well as to Gail LeBlanc for her continued expert copyediting and layout for each Issue. We have a good team working on behalf of the NSIS.

7. Membership Annual Report (H. Bird for Jinshan Xu):

Membership Overview:

To date, there are currently 127 active members of the NSIS, plus 10 institutional members. This is slightly higher than a year ago.

Type of Membership	**AGM 2023**	**AGM 2024**
Honorary	2	3
Life	26	29
Regular	76	60
Student	6	6
Complimentary (Lecturers, SSTCC)	17	22
	127	120
Institutional	10	3
	137	123

In discussion, Councillors and members were asked to submit ideas for increasing membership.

8. Librarian's Annual Report (Carol Richardson):

- ***Proc. N.S.I.S.:*** There were no sales of the *Proceedings* from June 2023 to April 2024. Print copies of the most recent issue were mailed to 7 members, others were hand-delivered.
- **Indexing & Abstract Services:** Complimentary copies of the most recent issue of the *Proceedings* were sent to the National Library of Canada (2 copies) & the US Library of Congress.

- **Access Copyright:** Payments received from Access Copyright were sent directly to the NSIS Treasurer.
- Institutional Members: Renewal invoices have been sent to 14 institutional Members of which 3 have renewed their subscriptions. An invoice for $12.52 was received in March 2024 for charges incurred by the Dalhousie Libraries for the mailing of invoices to Institutional members in October 2023.
- **NSIS Exchange Journal Collection:** NSIS receives journal issues from 81 Exchange Partners around the world. From June 2023 to April 2024, we received 21 journal issues and society publications. These items were processed by the Dalhousie Killam Memorial Library and added to the NSIS collection in the Library.

In discussion it was pointed out that eliminating the 6-month quarantine removed an incentive for non-Members to become Members. So to offset this, we have added a "banner" that appears when a person accesses an issue of PNSIS online. It points out the costs of producing the PNSIS, a refereed scientific journal, and encourages the reader to support it by becoming a Member.

It was also recommended that we post a list of our exchange partners and the names of the journals that they share on our website, along with how they may be accessed at the Killam Library.

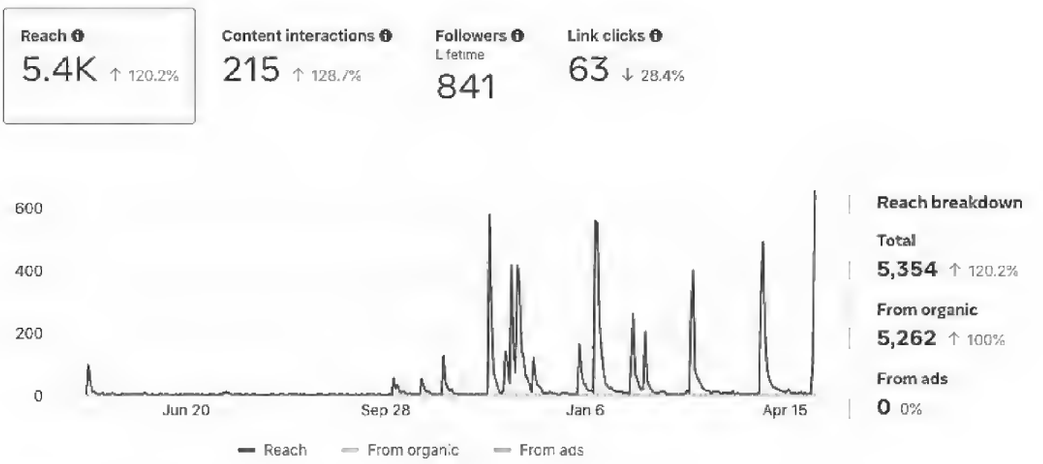
9. Publicity Annual Report (Brent Robichaud):

Highlights:

- The Publicity Officer generated annual promotional material for the lecture series including monthly printable posters, monthly social media banners, and our annual NSIS brochure (contains full list of seminars for the year and other NSIS information (e.g., how to become a member).
- He generated monthly Facebook events for each lecture. Also advertised monthly about the lecture series on Facebook, Twitter, and Instagram (~1–2 weeks before each lecture). Other content was posted to Facebook, Twitter, and Instagram as requested (e.g., posts about the writing competition).
- He e-mailed university science administrators about upcoming lectures each month.
- He set up a new Instagram account for the NSIS.

- The Publicity Officer worked with Past-President T. Franz-Odendaal and Councilor J. MacInnis to draft terms of reference for new suite of NSIS Awards. He also designed certificates for these new NSIS awards.
- He assisted in judging this year's Student Science and Technology Communication Competition and judging abstracts for the 2024 Student Research Symposium.
- He has been working alongside the website manager during the year to update website as requests come in.

Facebook: (past year: 1-May-2023 to 30-April-2024)
Assessment: In 2022/23 we had 491 page visits, in 2023/24 we had 840 page visits so about double from the previous year. We also gained 58 followers on FB this past year bringing our current total followers to 841.



Twitter: (Note that Twitter has removed free analytics)
Assessment: Based on the number of followers, we had 187 followers in May 2023 and in May 2024 we have 229 followers. Hence, a net gain of 42 Twitter followers this past year.

Instagram: (Note that this is our first year having Instagram)

Assessment: Since activating our Instagram account earlier this year we are at 104 followers.

10. Webmanager's Annual Report
(S. MacQuarrie for Romman Muntzar):
PayPal: We stopped using PayPal to receive payments and switched over to direct bank deposit.

Quarantine on Viewing New Issues of PNSIS: We removed the 6-month non-member quarantine to view online copies of new issues of PNSIS.

Interface with the Web Hosting Service: We transferred our account with our web hosting service to the Secretary, and we renewed our contract for 3 years.

Domain Name: We acquired an additional domain name, nsis.ca

Updates and Upgrades: We put considerable effort into making numerous updates and additions as circumstances required.

S. MacQuarrie thanked R. Muntzar and B. Robicheau for their efforts through the year to keep the website populated and up-to-date. She also reminded us that we need someone to fill the Webmanager position.

11. Lecture Series Annual Report (Alana Pindar):

This year was a very successful seminar year with a seminar in September! She noted that the YouTube channel with our past Lectures has a lot of traffic -- between 70 and 110 viewers per lecture. We also saw CBU hosting two seminars outside of HRM. This will continue into the 2024-2025 year and we encourage all other Institutes to host an NSIS seminar in the future.

This year we hosted our first student career event which saw over 50 participants from across Nova Scotia and experts from different career paths. Our panel included experts in conservation biology (Hannah de Loe - ACAP Cape Breton); Chemistry (Taylor Lynk - Solid State Pharma); Engineering (Sarah Evely - Project Manager at Pomerleau); and Healthcare (Dr. Isabel Smith - Dal Faculty of Medicine and Garry Dart - NS Health Authority).

We are excited to be wrapping up this year's seminar series with Dr. Jason Loxton Geologist at CBU.

Planning for the student events will begin in September 2024, we encourage Councilors to consider joining the student career, and/or student symposium organizing committees to help organize both events that will be held in 2025.

We wish to thank all of the 2023-2024 Seminar Speakers, student career event guests, students who participated in the students symposium, and of course all of our viewers!

2024-2025 Confirmed Seminar Series:

Month 2024/2025	Speaker	Location of Talk	Speaker confirmed
October	Dr. Shelley Denny from UINR	CBU	Yes
November	Dr. David Awde from MSVU	SMU	Yes
December	Dr. Erin Mazerolle from St. F.X	St. F.X.	Yes
January	Student Q & A on careers	Online	
February	Mr. Fred Beachler - Senior Hydrologist at ADI	CBU	Yes
March	Student Symposium	SMU	
April	Dr. Art MacDonald	SMU	Yes
May	Dr. Lori Borgal from MSVU	SMU	Yes

A. Pindar requested that suggestions for the 2024-2025 Series be sent to her as soon as possible.

12. Student Science & Technology Communication Competition Annual Report (Jillian Phillips and Jinshan Xu):

This year's competition remained similar to last year in format with an open call for essays focussed on a science, technology, math, or social science topic, however, new this year was the addition of a high school category to extend our outreach to NS students.

The overall goals of the competition were as follows:

- Promote communication of science and technology in NS
- Encourage students to engage with the NSIS and become new members.
- Provide an opportunity to practice STEM communication skills and receive meaningful feedback on their writing
- Generate interest and submission for publication within the Proceedings of the NSIS

Student Stats:

- 29 students registered for the competition
- 14 papers were submitted at the close of the competition
- 5 high school essays were submitted from four NS schools:
  Cobequid Education Centre
  Halifax Grammar School
  Horton High School
- 9 Post-secondary Essays were submitted across 6 Universities:
  Dalhousie University (2)
  Cape Breton University (2)
  Mount Allison University (1)

Mount St. Vincent University (2)
St. Francis Xavier University (1)
St. Mary's University (1)

- Two winners and three honorable mentions were selected based on scoring and judges' feedback:

The winners of the 2024 SSTCC are:

Christelinda Laureij is a Nova Scotia Student completing their 4th year in the BSc program at Mount Allison University with a focus on Biology and Biochemistry.
Paper title: The effect of insulin on neuronal activity in the rat dorsomedial hypothalamus

Kara Lee is a grade 10 student attending Halifax Grammar School and our competition has piqued her interest in science.
Paper title: Reinforcing the Dam: What Valve-Development in Cattle Can Tell Us About the Failing Human Heart

The following students deserve an honorable mention for their submissions:

Madison Power (2nd place runner up) is a 1st year BSc. (Chemistry) student at Cape Breton University.

Paper title: An Investigation into the Effectiveness of Maskwi'omin (Betula papyrifera oil) on Bacterial Growth Inhibition Compared to Vancomycin

Salvatore Avvampato is a 3rd year BSc. (Kinesiology) student at Dalhousie University
Paper title: Adapting baseball pitchers' behaviours to reduce injury while maintaining accuracy

Owen Jones is a grade 12 student at Horton High School.
Essay Title: Electric planes; Why the Future of Aviation is Inevitably Electric

It was suggested that these students be featured on the NSIS website, possibly with a copy (or the abstract) of their papers.

Feedback and Considerations for next year:

- The competition's coordinators recognize that although the competition called for an essay format, the writing guidelines and rubric guided students toward a research paper/ journal article style submission. The coordinators and judges agree

that the rubric should be further revised to better align with an essay category and there was interest to keep the current rubric for future use and bring back a research-focussed category.

- The judges suggested allowing students to pick which category they want to partake in (essay or research article) and the coordinators would provide the guidelines and rubric to reflect their choice.
- To further refine the competition guidelines and provide more consistency between paper formats, it is suggested that next year, only one reference style is accepted. The suggestion is to use the style reflected in the PNSIS as our example.
  • The preference if for work cited to be from primary literature, however, its recognized that high school students may not have access or know where to find reliable sources. Brent suggested adding a section on the website with resources on where to find open access primary literature (e.g. Google Scholar, PNSIS, and other open access links)

Other suggestions:

- Flesh out the bonus point section for NS relevance a bit more (e.g. specific research taking place within NS, a public health issue in NS, impact on NS or NS-centered issue being addressed).
- Semantics change: change the name of the competition back to the "Student Science and Technology Writing Competition" since the additional communication pieces such as the video and media summary have been dropped from the requirements.

The coordinators would like to thank all the students who participated and all those who made the competition possible. A special thank you goes to our generous donors: Cape Breton University, Engineers Nova Scotia, and Saint Mary's University. Many thanks to Jinshan Xu for his support during the early phase of setting up the competition to and Hank Bird, for creating comprehensive score sheets to capture judges' feedback and guide our decision making. Thank you to our judges Audrey Salinger, Aveena Herold, Barbara Zielinski, Brent Robicheau, Hank Bird, Jinshan Xu, and Reid Sutherland. And thank you to Anne Dalziel and Hank for presenting the awards in our absence during the April public lecture.

J. Phillips expressed her pleasure leading the competition the past two years and she looks forward to how it blossoms under a new coordinator next year. She respectfully pases the torch to Shannon Ezzat to lead next year and is happy to offer her support.

13. Excursions Annual Report (Hank Bird):

We did 16 excursions between 2016 and 2023, with a break from 2020-2022 due to Covid-19.

In April 2023 we had a pop-up joint excursion sponsored by the NS Museum of Natural History, which was an urban geology walk on the Halifax Citadel drumlin.

In July 2023 about 10 people went to Kejimkujik National Park for a guided outing to include the petroglyphs and a nature hike.

We, with the assistance of Bruce Hatcher, have scheduled an excursion to Scatarie Island for July 13th. We are expecting a full complement of about 20 members and guests.

We are working with Dr. Linda Campbell of SMU to do an outing to a historical gold mine in the Halifax region later in July. The objective is to learn about historical gold mining in NS and the resulting remediation efforts required.

We are considering arranging a joint event or two with the Halifax Field Naturalists organization, which has field trips and lectures.

Other possibilities include:

- Waterfalls of Nova Scotia (various sites)
- Shubenacadie Wildlife Park (Shubenacadie)
- Cape Split Nature Hike (Scots Bay)
- NS Museum of Industry (New Glasgow)
- Canadian Geological Association (joint excursion) (TBD)

We welcome additional suggestions.

For the record, these are the 16 excursions we had in 2016, 2017, 2018, 2019, 2022, and early 2023:

- Annapolis Royal Historic Gardens (twice)
- Bedford Institute of Oceanography
- Burke-Gaffney Observatory
- Dalhousie Planetarium
- Discovery Centre (including "behind the scenes")
- Fundy Geological Museum, Ottawa House, and the Tidal Power Exhibit.

- Habits and Habitats of NS Birds
  (in association with the NS Birding Society)
- Halifax Citadel Drumlin Geological Walk
- Joggins Fossil Cliffs
- Kejimkujik Petroglyphs and Nature Walk
- Natural History of McNab's Island
- Otter Ponds Demonstration Forest
- Purcell's Cove Backlands
  (in association with Halifax Field Naturalists)
- Shubenacadie Canal
- The Science and Art of Making Beer, at the
  2 Crows Brewing Company
- The Science and Art of Making Beer
  (one at the Garrison Brewery, another at
  2 Crows Brewing Company)

14. Motion to Accept the Annual Reports:
Moved: by H. Bird
Seconded: by M. Paon
All in favour: Approved unanimously.

15. Awards – Recognition of New Honorary Member: (S. MacQuarrie)

Per the by-laws, a Nova Scotian person distinguished in some branch of science or who has rendered conspicuous service to the advancement of science can be elected an Honorary Member.

Dr. Jeff Dahn of Dalhousie University is one of the pioneer developers of the lithium-ion battery and has had a worldwide impact. He established a world-leading centre of battery science at Dalhousie, and has trained a generation of students, more than 140. He had a partnership with 3M Corporation, and is currently partnering with Tesla Inc. Jeff has received numerous and significant Canadian and international awards. He has also given at least one of our public lectures. In January 2024 the Council unanimously elected him an Honorary Member of the NSIS.

Congratulations Dr. Dahn, recognizing your exemplary academic research in lithium-ion battery technology, the relevance of your research to anthropogenic climate change adaptation, and the very positive impact you have had on many young scientists – we welcome you as an Honorary member of the NSIS!

16. **Awards – New NSIS Awards & Presentations: (Judy MacInnis)**
A committee considered and recommended a slate of new NSIS awards, and the Council has adopted them. They comprise:

- Service Awards: Dedicated Service (regular + trainee), Exceptional Service
- Travel Award
- Early Career Award
- Editor's Choice Award
- Best Talk Award
- STEAM Award (junior and senior)

At this time, the committee and council make the following Service Awards:

Dedicated Service (regular): 5 yrs+
Hank Bird
Tamara Franz-Odendaal
Angelica Silva
Peter Wells

Dedicated Service (trainee): 2 yrs+
Romman Muntzar
Brent Robicheau

Exceptional Service (non-Councillor):
Gail LeBlanc
Carol Richardson
David Richardson

17. **By-Laws: (S. MacQuarrie)**
A draft of the amended By-laws was e-mailed on 19 April 2024 for perusal by all NSIS Members.

The revised bylaws are as follows:

- Revisions arising from changes in the relationship between the NSIS and the Dalhousie Killam Library.
- A small change in criteria for Honourable Membership arising from the establishment of new NSIS Awards.
- A slight relaxation in the limits to terms of office for Council Offices.

The text of the changes are as follows, with deletions in red (strikethrough) and additions are in green. (Note that the changes result in re-numbering of some articles.)

Library-Related:

2. The objectives of the Society are to represent and promote science. This is done by holding regular public meetings, by publication of work in its Proceedings, by retaining a library of journals housed at the Dalhousie Killam Library, and by maintaining databases, and a website which includes a Hall of Fame.

16. The officers of the Institute shall consist of a President, a Vice-President, a Past-President, a Secretary, a Treasurer, a Publicity Officer, a Membership Officer, an Editor, a Library Liaison Officer, a Webmanager and a Speaker Series Chair. In some cases, one individual may hold two offices.

17. The officers, shall be elected each year at the Annual General Meeting of the Institute and shall hold office until the next Annual General Meeting or until their successors are elected. The tenure of officers, except the Editor, should not normally exceed five (5) years.

19. The Nominating Committee shall present in writing at the Annual General Meeting nominations for:

    a. officers-
    b. other members of Council;
    c. auditor(s) or appropriate person(s) to review the accounts of the Institute; should no nominations be made, Council may appoint such person(s);
    d. and nominees to government commissions.

    No member shall be nominated unless their consent has been received by the Nominating Committee.

    Notwithstanding that the Editor may serve for more than 5 years, the Nominating Committee shall, as a courtesy, consult annually with the Editor.

Library Liaison Officer

29. The Library Liaison Officer shall:
    a. ensure that paper copies of the latest issue of Proceedings have been delivered to the Killam Library for filing and storage, and for availability on the Library's website;
    b. ensure that requests from individuals to purchase issues of the Proceedings or acquire articles have been satisfied;
    c. ensure that correspondence to the Institute arising from the mailing of the Proceedings to Institutional Members and Exchange Partners is distributed to the appropriate Officer;
    d. verify that journals received from Exchange Partners have been received, catalogued and shelved by the Killam Library;
    e. verify that annual invoices to Institutional Members have been sent by the Membership Officer;
    f. verify that the current mailing list, maintained by the Membership Officer, of Institutional Members and Exchange Partners for distributing the Proceedings is up-to-date;
    g. submit a Repertoire Payment Form to Access Copyright annually;
    h. prepare an Annual Report for presentation at the Annual General Meeting.

35. The Council shall consider and decide on nominations for admission to the web-based Hall of Fame based on recommendations from a Committee that includes that includes two members of Council and at least one other member with expertise in the scientific area of the nominee. Nominees shall be deceased scientists of distinction, who had a tangible connection to Nova Scotia.

Awards-Related:

7. Any member distinguished in some branch of science or who has rendered conspicuous service to the advancement of science in Nova Scotia, is eligible for nomination and election as an honorary member. Nominations must be submitted to the Council in writing, be signed by three (3) members in good standing and be accompanied by a document presenting the

reasons for awarding the honour. Election of candidates shall require the support of a majority of Council members.

Term-of-Office-Related:

17. The officers shall be elected each year at the Annual General Meeting of the Institute and shall hold office until the next Annual General Meeting or until their successors are elected. The tenure of officers, except the Editor, should not normally exceed five (5) years.

18. **Motion to Approve the New By-laws:**
Moved: by S. MacQuarrie
Seconded: by B. Hatcher
All in favour: By-laws approved unanimously.

19. **Increase in Regular Membership Fees (S. MacQuarrie)**
A letter concerning a proposed increase in fees was e-mailed on 19 April 2024 for consideration by all NSIS Members.

Due to declining financial assets and increased inflationary pressures, the NSIS Council recommends that the annual fees for Regular Members be raised by $10 per year.

Thus, the new rates would be:

Student Member	$10 per year
Regular Member	$40 per year
Life member	$300 one-time

20. **Motion to Approve the New Membership Fees:**
Moved: by D. Richardson
Seconded: by M. Paon
All in favour: Fees Approved unanimously.

21. **Report of the Nominating Committee for the 2024-2025 Council: (S. MacQuarrie)**
The President thanked the outgoing Council. The AGM was asked to elect the following to NSIS Council for 2024-2025:

Officers:

President	Jillian Phillips
Vice-President	Stephanie MacQuarrie (acting)
Past President	Stephanie MacQuarrie

Treasurer	Angelica Silva
Editor	Peter Wells
Librarian Liaison	------ C. Richardson will support)
Membership	Jinshan Xu
Webmaster	------ (open)
Publicity Officer	Brent Robicheau
Secretary	Hank Bird
Speaker Series Chair	Alana Pindar
Councillors:	
Councillor	Barbara Zielinski
Councillor	Bruce Hatcher
Councillor	Judy MacInnis
Councillor	Shannon Ezzat
Councillor	------ (St.F.X. open)
Observers:	
Nova Scotia Museum	Tim Fedak
Discovery Centre	------ (open)
Schools	------ (open)
Acadia	Courtney Strugnell
CBU	Adam Brown
Student Rep.	Audrey Salinger (SMU)
Associate Editor:	David Richardson

22. Motion to Approve the Nominations:
Moved: by B. Hatcher
Seconded: by H. Bird
All in favour: Nominations approved unanimously.

23. Any Other Business:
There was no other business to conduct.

24. Adjournment:
Moved by S. MacQuarrie to adjourn the 163rd Annual General Meeting of the NSIS at 7:35 pm.

Respectfully submitted,
Hank Bird, Secretary

NSIS 2024-2025 LECTURE SERIES NSIS1862.CA

October 7 – CBU

The Impact of Cape Breton's Changing Climate on its Fresh Water Resources

Fred Baechler
Hydrogeologist/
Hydrologist at EXP
Services Inc.

Mr. Baechler has been undertaking research on Cape Breton's changing **climate** and the impact on its **freshwater resources** for over 25 years. This lecture will identify how Cape Breton's climate is changing and what is known to date about how it is impacting the island's ground and surface resources.

November 4 – MSVU

How do insects stretch their physiological limits in response to environmental stress?

Dr. David Awde
Mount Saint Vincent
University

Increasing global temperatures and frequency of extreme weather events are likely outpacing the ability of most animals to adequately respond. Dr. Awde will explore the environmental and physiological mechanisms that influence **insect responses to temperature change**, and discuss future work that will compare and contrast these mechanisms using **native and invasive species**.

December 2 – StFX

Heart Health is Brain Health

Dr. Erin Mazerolle
St. Francis Xavier
University

How can we keep the mind sharp as we age? What is **dementia**, and can it be prevented? Why is it important to talk to a healthcare provider if you are noticing problems with **thinking** or **memory**? Dr. Mazerolle will help answer these questions by describing the tight relationship between **heart health** and **brain health**.

January 6

Careers in Science: Panel Discussion with Nova Scotian Scientists

Online Only! @6:30pm

All lectures will be hybrid events held at St. Mary's University (Stephanie MacDonald Lecture Theatre, SMU Atrium 101) and on line via Zoom links that will be posted one week before each seminar on the NSIS Public Lectures webpage .

1ST MONDAY OF EVERY MONTH 7:30 PM @NSInstituteofScience @NSIS_Sci_NS

February 3 – CBU

Ankukamkua'tu, 'doing treaty', in Fisheries

Dr. Shelley Denny
Unama'ki Institute of Natural Resources

Despite the recognition of the treaty right to fish for a moderate livelihood in 1999 little movement toward enhancing governance occurred that respected the authority of both the Mi'kmaq in N.S. and the Department of Fisheries and Oceans. As a result, the **moderate livelihood fishery** is contested on the water and land. Dr. Denny will explore how the Mi'kmaq and DFO could govern Mi'kmaw treaty fisheries using **Two-Eyed Seeing**.

March 3 – SMU

Student Symposium

Join us as we discover the latest research findings of **student scientists** working at nearby N.S. research institutions.

We thank our partners who have joined us in our journey and mission to promote research and education in science...

April 7 – CBU

Understanding the Universe and its Evolution from 2 km Underground

Dr. Arthur McDonald
Queen's University
Nobel Physics Prize 2015

There has been remarkable progress in the past 60 years in understanding the **evolution of the Universe** since the **Big Bang**. Major contributions are being made by measurements in deep underground laboratories like SNOLAB, near Sudbury, Ontario. The lowest radioactivity lab on Earth. Measurements of **neutrinos** and **Dark Matter** will be described that address existential questions about the composition and evolution of our Universe.

May 5 – SMU

Stem cell proliferation gone wrong: Mechanisms exploited in cancer cell proliferation

Dr. Lori Borgal
Mount Saint Vincent University

During **human development**, stem cells must proliferate in a precisely controlled manner, failure can result in tissues such as the brain not forming correctly. Dr. Borgal will introduce molecular mechanisms required for **stem cell proliferation**, and consider how disruption of these same mechanisms could lead to uncontrolled cell proliferation in **cancer**.

NOVA SCOTIAN INSTITUTE OF SCIENCE

MEMBERSHIP FORM 2024-2025

Please fill out and make copy, then forward in mail together with membership fee.

Name: _____

Address: _____

_____

_____

Phone: H _____ W _____

Email: _____

If this membership is being purchased on behalf of another individual, please insert that person's name here:

_____

Memberships (please check one):

Regular member $30 _____

Student member $10 _____

Life membership $300 _____

Enclosed is cheque for _____ to cover dues for _____ years.

Voluntary Donation (Tax receipt will be issued): _____

Mail to:

Attention: Treasurer, Nova Scotian Institute of Science
c/o Reference and Research Services
Killam Memorial Library | 6225 University Avenue
PO Box 15000 | Halifax, NS Canada B3H 4R2

NSIS1862.CA

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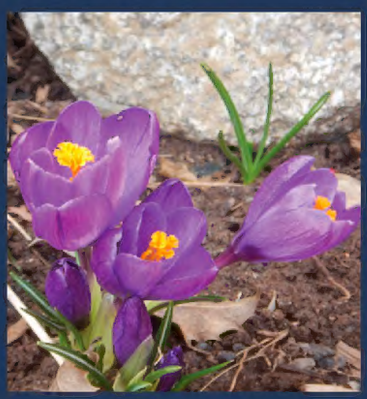

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